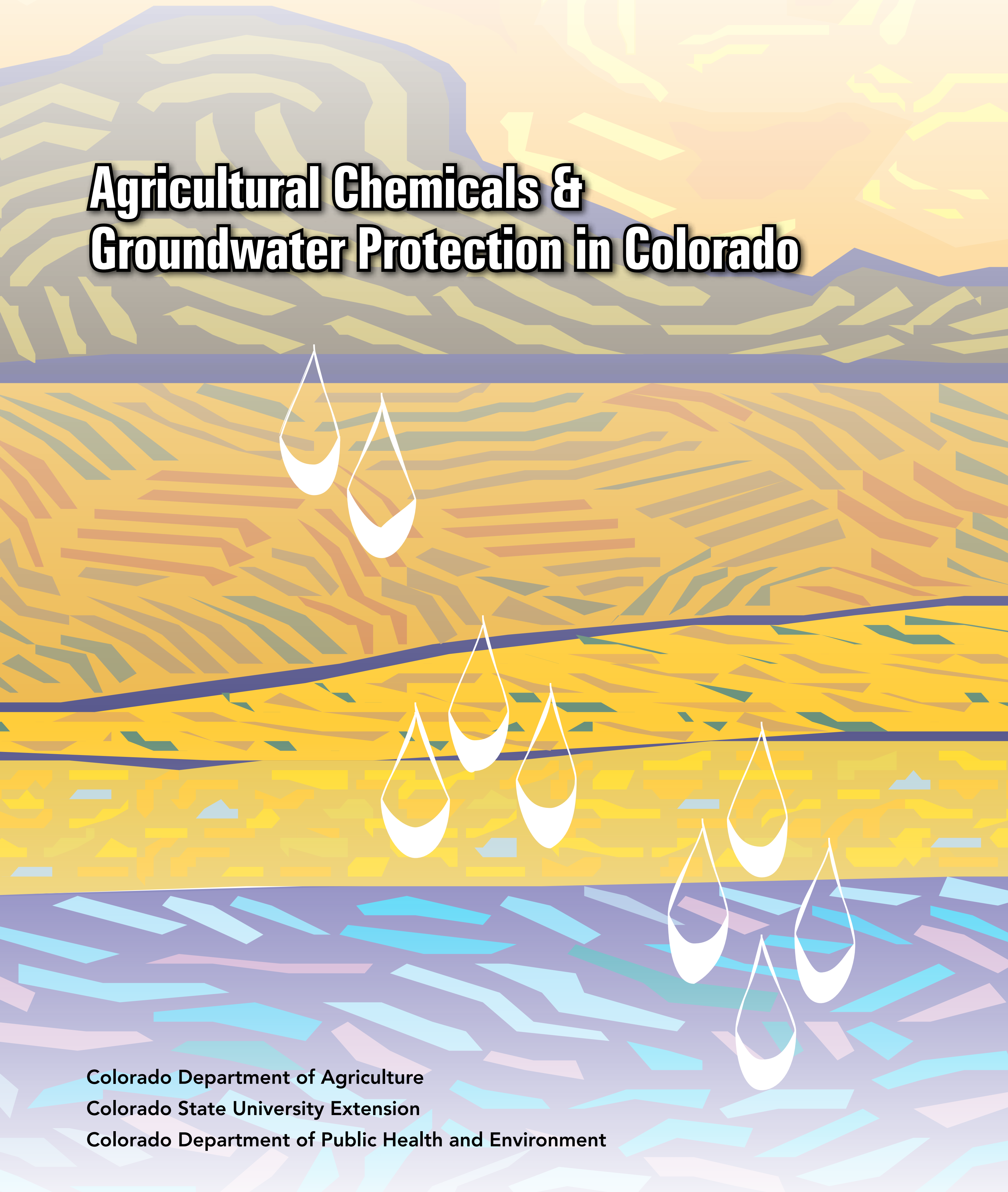
Colorado Water Institute
Special Report No. 23

Agricultural Chemicals & Groundwater Protection in Colorado



Colorado Department of Agriculture
Colorado State University Extension
Colorado Department of Public Health and Environment

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Acronyms

AES	Agricultural Experiment Station (Colorado State University)
AMA	agricultural management area
AMP	agricultural management plan
ARS	Agricultural Research Service (United States Department of Agriculture)
BDL	below detection limit
BMP	best management practice
CCA	Certified Crop Advisor
CDA	Colorado Department of Agriculture
CDPHE	Colorado Department of Public Health and Environment
CSUE	Colorado State University Extension
DEA	desethyl-atrazine
EPA	Environmental Protection Agency
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
LEPA	low-energy precision application
MCL	maximum contaminant level
MDL	minimum detection level
NASS	National Agricultural Statistics Service (United States Department of Agriculture)
NAWQA	National Water-Quality Assessment Program (United States Geologic Survey)
NO_3-N	nitrate nitrogen
NRCS	Natural Resources Conservation Service (United States Department of Agriculture)
PAM	polyacrylamide
PBB	parts per billion or micrograms per liter
PMP	Pesticide Management Plan
PPM	parts per million or milligrams per liter
PVC	polyvinylchloride
PSNT	pre-sidedress nitrate testing
PSW	Public Supply Wells
RUP	restricted use pesticide
SDWA	Safe Drinking Water Act
SLVEC	San Luis Valley Ecosystem Council
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WQCC	Water Quality Control Commission (Colorado Department of Public Health and Environment)
WQCD	Water Quality Control Division (Colorado Department of Public Health and Environment)

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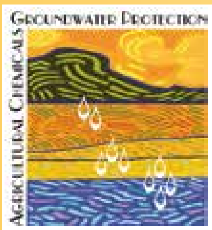

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The authors of this publication want to acknowledge the dedicated efforts of several state and local advisory committees and workgroups. In particular, the members of the Groundwater Protection Program Advisory Committee have offered significant input and volunteered time and travel to guide program staff toward relevant work in protecting water quality. The following individuals have served on this committee:

David Brown, Tess Byler, Nathan Coombs, Mike Deardorff, Lanny Denham, Anthony Duran, Steven Eckhardt, John Eden, Ray Edmiston, Andrew Ferguson, Barbara Fillmore, Clay Fitzsimmons , Steven Geist, Bob Gobbo, Wayne Gustafson, John Hardwick, Roger Hickert, Rich Huwa, Jim Klein, Terry Kohler, Mark Krick, Dave Latta, Jim Lueck, Mark McCuistion, Jerry Mc Pherson, Darrel Mertens, Mike Mitchell, Roger Mitchell, Eugene Pielin, Tom Pointon, Mike Rahn, Brett Rutledge, Don Rutledge, Robert Sakata, Max Smith, Steve Sackett, Bruce Sandau, Kenny Smith, Martin Spann, Monte Stevenson, John Stout, Harry Talbott, Barbara Taylor, Jack Villines, Lloyd Walker, Doug Wilson, John Wolff, Les Yoshimoto, and Leon Zimbelman, Jr.

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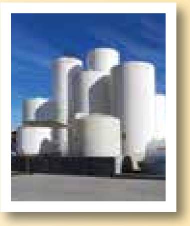
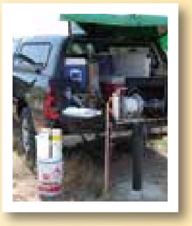
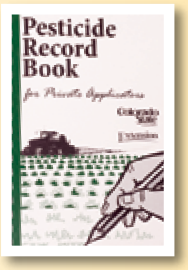






Agricultural Chemicals & Groundwater Protection in Colorado

The Agricultural Chemicals and Groundwater Protection Program was created during the 1990 legislative session and took effect on July 1, 1990. The Program's purpose is to reduce negative impacts agricultural chemicals have on groundwater and the environment by preventing groundwater contamination before it occurs through improved agricultural chemical management. Agricultural chemicals covered under this legislation include commercial fertilizers and all pesticides. This report summarizes the efforts of the Agricultural Chemicals and Groundwater Protection Program since inception and provides an overview of activities and monitoring data.

The program employs three primary functions to protect groundwater in Colorado:

1. Regulation
2. Groundwater monitoring
3. Education and training

Program Oversight and Regulation

The Colorado Department of Agriculture (CDA) is the program's lead agency. One of the CDA's responsibilities is to regulate agricultural chemical bulk storage and mixing/loading. Pesticide facility inspections began Sept. 30, 1997, and fertilizer facility inspections began Sept. 30, 1999. More than 1,800 inspections have been performed at facilities throughout the state.

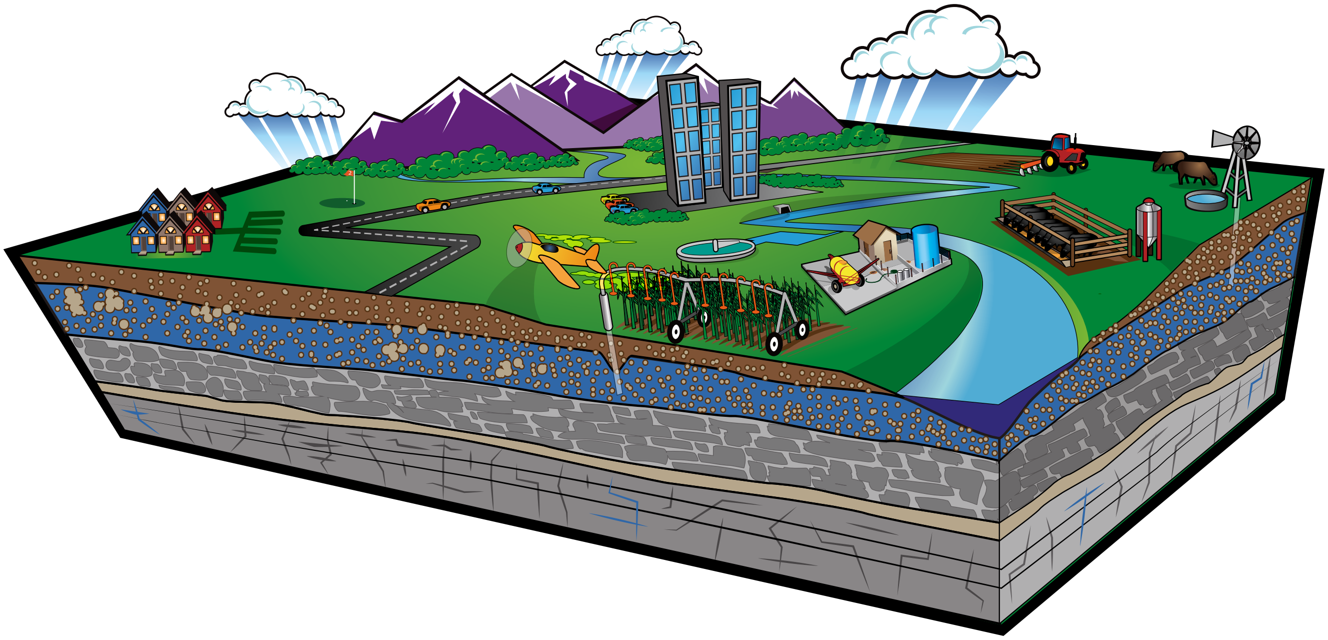
As part of program oversight, the CDA also facilitates a pesticide waste collection program. Initiated in 1995, the program has collected more than 100,000 pounds of waste pesticide from public and private sources.

Groundwater Monitoring

The monitoring program prioritizes its sampling in areas where agriculture is the predominate land use. These data form the backbone of the Groundwater Protection Program. They determine the need and priority for education and other program resources. The program has completed sampling of groundwater systems in the largest agricultural and urban regions of Colorado:

- South Platte River Basin
- San Luis Valley
- Arkansas River Basin
- Front Range Urban
- High Plains
- West Slope (Western Colorado)
- North Park Basin
- Wet Mountain Valley
- Mountainous Region

Monitoring data, vulnerability assessments, and chemical use survey data indicate there are areas in Colorado where water quality still is susceptible to contamination. Fortunately,



Groundwater quality protection requires monitoring, research, education, and training in a variety of land uses in the watershed.

the majority of wells sampled thus far are not contaminated at levels deemed unsafe for human consumption by the Environmental Protection Agency (EPA).

Education and Training

The legislation creating the Agricultural Chemicals and Groundwater Protection Program specifies that the Commissioner of Agriculture is authorized to enter into an agreement with Colorado State University Extension (CSUE) to provide education and training on how to reduce groundwater contamination from agricultural chemicals [C.R.S. 25-8-205.5(3)(f)]. CSUE works with the CDA to develop best management practices (BMPs) for Colorado farmers, landowners, and commercial agricultural chemical applicators. CSUE has produced numerous publications on best management practices, or BMPs, and helped pilot the local BMP development process.

CSUE uses other avenues to provide information, such as applied research, field days, demonstration sites, continuing education through the Certified Crop Advisor program, a display booth, videos, and the Groundwater Protection Program website.

In order to assess the BMPs adopted by Colorado's agricultural producers, several surveys have been conducted, most recently in 2011. Overall, results of the surveys suggest producers accept many of the irrigation, pesticide, and nutrient management BMPs that help protect water quality and farm profitability. Nutrient and pesticide management BMP adoption is generally higher than irrigation management BMP adoption. Irrigation system improvements, or structural BMPs, are common in most regions, but adoption of irrigation management BMPs used to determine when and how much to water is not as common.

Future Direction

Predictions are that population growth and urbanization, coupled with increasing land and water values, will reduce the number of acres devoted to irrigated crop production in several river basins (SWSI, 2010). These trends may also change cropping patterns from large acreage, low value crops to smaller acres of higher value crops. Often, these crops require different levels of pesticide and fertilizer inputs.

Like much of the West, Colorado is experiencing an increase of small acreage 'ranchettes' as larger farms and ranches are subdivided. The result is that one landowner may be replaced by many more individuals on the same land area. These land use changes may also affect Groundwater Protection Program activities and resources as the new rural residents also impact water resources through their land management activities. Thus, changes in educational and monitoring efforts will be required to protect groundwater quality under these new land use environments.

Additionally, the increasing and changing population dynamics in Colorado may refocus the educational and monitoring programs from primarily agricultural to urban and exurban areas. Keeping partnerships with federal, state, and other agencies working in water resource protection will continue to be critical, but other partners also may need to be considered, such as municipalities, the green industry, and other entities that work more in the urban environment.

The Groundwater Protection Program has been working with agricultural producers, the agricultural chemical industry, and several state and federal agencies to prevent contamination of Colorado's groundwater resources from point and nonpoint source pollution for more than two decades. This cooperation serves a good model for other programs working to protect Colorado's water for future generations. BMP adoption results and groundwater monitoring data indicate these efforts are working to protect groundwater quality in Colorado.

Agriculture and water are inseparable in a semiarid region such as Colorado. Adequate clean water supplies for drinking, agriculture, industry, and recreation are critical for the lifestyle Coloradans enjoy.

Water resources are found in surface water and groundwater. Each is unevenly distributed across the state and quality varies considerably.

Surface water is the dominant water source in Colorado because of its availability and relative ease of diversion. The state's location in the heart of the Rocky Mountains results in large quantities of surface water from snowmelt. Runoff provides drinking water supplies for most Coloradans. Less than 18% of Colorado's 5.6 million residents rely solely on groundwater (Rein, 2012).

However, groundwater is critical for residents where no other reliable water sources exist. Colorado's eastern plains, parts of the San Luis Valley, and sections of Adams, Arapahoe, and Douglas Counties are especially dependent. In these areas, the communities and rural residents depend on the resources' preservation. In addition, rapid population growth and land development in the rural foothills, mountains, and along the Front Range are increasing the number of people who rely on groundwater.

Groundwater occurs throughout Colorado, but usable supplies are generally found in aquifers, or porous geologic formations. Three types are predominant in Colorado:

1. Alluvial aquifers—formed in materials deposited in a stream/river channel or floodplain or coarse, colluvium outwash material
2. Sedimentary rock aquifers—formed in consolidated and/or unconsolidated sedimentary formations
3. Mountainous region aquifers—formed in the fractures, joints, and faults of crystalline igneous and metamorphic rocks in the mountains (Topper and others, 2003)

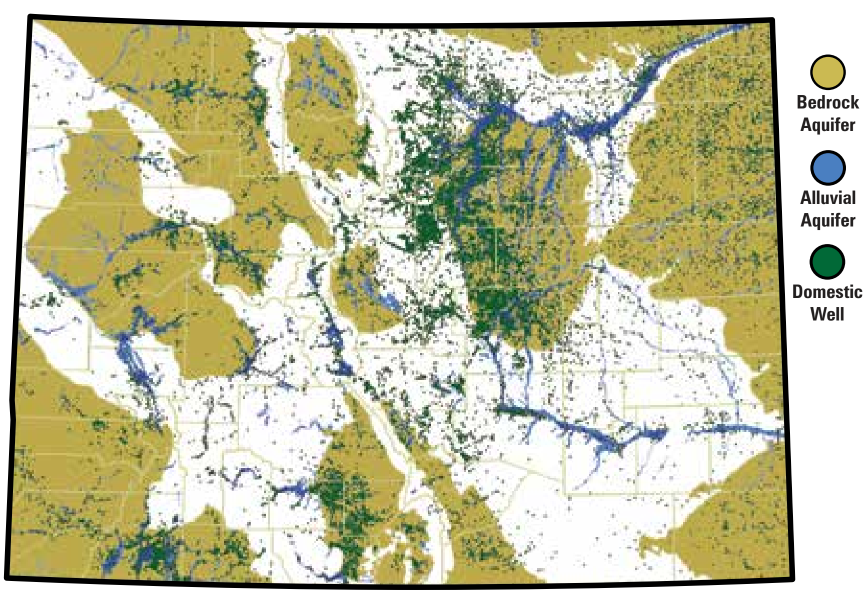
Much of the groundwater is found and used in areas where intensive crop production occurs, such as the High Plains, San Luis Valley, and the South Platte River Valley. Agriculture withdraws an estimated 82-85% of Colorado's groundwater (Wolfe personal communication, 2006).

As of December 2005, the State Engineer reports approximately 234,000 permitted wells in Colorado, along with an estimated 5,000–10,000 wells without permits constructed before 1972. Of the total 234,000 permitted wells, more than 150,000 are residential and household wells; 2,400 are municipal (Wolfe, 2006).

Total groundwater pumping in Colorado is approximately 3.1 million acre-feet of groundwater per year (one acre-foot = 325,900 gallons), which represents only 17% of the total 18 million acre-feet diverted annually in Colorado (Wolfe, 2006). Additional information on Colorado's aquifers and groundwater resources can be found in the Colorado Geological Survey's Ground Water Atlas of Colorado (Topper and others, 2003).

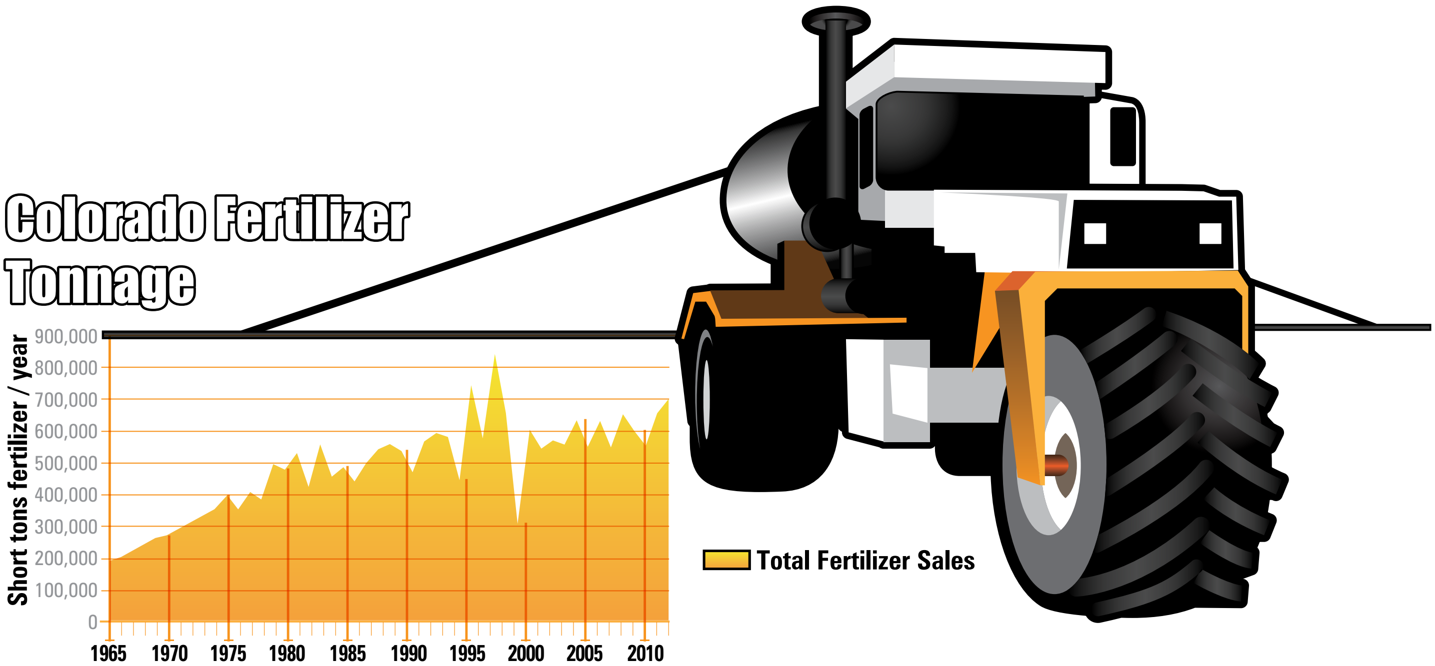
Although surface water is the dominant water resource in Colorado, groundwater is essential to the communities, businesses, farms, and residents who rely on it. Colorado's groundwater is a finite resource. If aquifers become contaminated, a valuable resource is lost. Therefore, the protection of the state's limited groundwater resources is an important function.

Colorado Domestic Use Wells



surface water: *water sources open to the atmosphere, such as rivers, lakes, and reservoirs*

groundwater: *supply of fresh water found beneath the earth's surface, usually in aquifers, which is often used to supply wells and springs*



> **point source pollution:** *sources of pollution that originate from a single point, such as a discharge pipe or ditch*
>
> **nonpoint source (NPS) pollution:** *pollution sources which are diffuse and do not have a single point of origin, such as agriculture, forestry, and urban runoff*

Regulatory Background

In the 1960s, studies linking the insecticide DDT—dichloro-diphenyl-trichloroethane—to declines in bald eagle populations created widespread public concern about pesticides' potential environmental impacts. In 1979, the discoveries of pesticide contamination from aldicarb in New York and from DBCP, or dibromochloropropane, in California led to the realization that groundwater was also susceptible to pollution from standard agricultural practices.

Beginning in the 1980s, public awareness began to emerge of the magnitude of water quality impacts from pollution sources other than discharge pipes, or point sources. As additional sources of pollution, or nonpoint sources, were studied, agriculture was identified as a significant contributor to surface water problems, especially due to soil erosion.

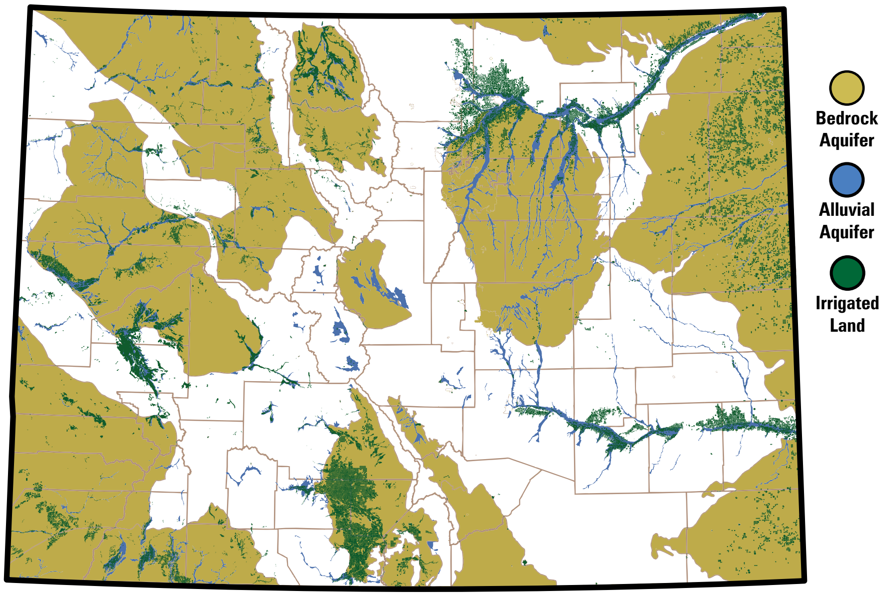
In Colorado in the 1980s, very little data existed to alleviate or confirm public concerns about pesticide and fertilizer's effects on water quality. In accordance with federal requirements, the Colorado General Assembly adopted the Colorado Water Pollution Act in 1966. Then, in 1973, legislators completely rewrote and renamed it the Colorado Water Quality Control Act to comply with new federal laws. A second total rewrite was adopted in 1981. The need to address water pollution from agricultural operations and other nonpoint sources was recognized both nationally and in Colorado by the mid to late 1980s.

The U.S. Department of Agriculture 2007 census data show Colorado's $6 billion agriculture industry encompasses approximately 37,000 farms and ranches that cover more than 31 million of the state's total 66 million acres. An estimated 2.9 million acres are irrigated and intensively farmed for a variety of crops and forages, utilizing inputs of pesticides and commercial fertilizers to achieve high yields.

Pesticide and fertilizer use are an important component of agricultural practices. The 1997 CDA Pesticide Use Survey reported about six million pounds of pesticide active ingredients were applied by commercial applicators who responded (Matti, 2001). Total—both commercially and privately applied—pesticide use is estimated at more than 11 million pounds of pesticide active ingredients. In 2011, there were 11,970 pesticide products registered for use in Colorado by 1,244 registrants, compared to 8,341 products by 880 registrants in 1990.

The 2007 USDA census reported combined annual production expenses for fertilizer, lime, soil conditioners, and chemicals exceed an estimated $201 million in Colorado (USDA, 2007). Fertilizer use in Colorado has increased from less than

Colorado Irrigated Agriculture



200,000 tons in the mid-1960s to more than 800,000 in the late 1990s (See facing page). High fertilizer prices, combined with drought, caused a 50-plus % drop in use in 2001. Since then, total use has averaged about 590,000 tons per year.

In 1990, the Rocky Mountain Plant Food and Agricultural Chemicals Association—now known as the Rocky Mountain Agribusiness Association—gathered support in the General Assembly for the passage of proactive legislation to address the potential for groundwater contamination from pesticides and fertilizers. Sen. Tom Norton (R-Greeley) sponsored Senate Bill 90-126, which amended the Colorado Water Quality Control Act to establish the Agricultural Chemicals and Groundwater Protection Program. The amendment established provisions to grant the CDA new authority to protect groundwater. While the Water Quality Control Division of the Colorado Department of Public Health and Environment is the state's primary water quality agency, the CDA has a long history of regulating the pesticide and fertilizer industries. Its existing inspection programs, created under the Federal Insecticide, Rodenticide, and Fungicide Act (FIFRA) and the Colorado Pesticide Act, allow the CDA to work with the pesticide and fertilizer industries to help administer the Agricultural Chemicals and Groundwater Protection Program.

Agricultural Chemicals and Groundwater Protection Program Legislation

The Agricultural Chemicals and Groundwater Protection Program created under C.R.S. 25-8-205.5 took effect on July 1, 1990. This legislative act states: *"…the public policy of the state is to protect groundwater and the environment from impairment or degradation due to the improper use of agricultural chemicals while allowing for their proper and correct use…"* (Colorado Revised Statutes, 1990. Legislative Declaration).

The implementation of this new law was originally funded by a 50-cent per ton tax on fertilizer sales and an annual $20 per product fee for pesticides registered in the state. The $20 pesticide registration fee increased to $30 in September 2005, after legislative changes were made to the statute that moved the fee setting authority from the Colorado General Assembly to the Colorado Agricultural Commission. The pesticide registration fee was increased by the Colorado Agricultural Commission in 2009 to $40.

The Groundwater Protection Program's work is defined by two classes of chemicals, pesticides and commercial fertilizers.

Pesticides are defined as *"any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest or any substance or mixture of substances intended for use as a plant regula-*

best management practice (BMP): *any voluntary activity, procedure, or practice…to prevent or remedy the introduction of agricultural chemicals into surface or groundwater to the extent technically and economically practical*

agricultural management area (AMA): *designated geographic area defined by the Colorado Commissioner of Agriculture where there is a significant risk of contamination or pollution of groundwater from agricultural activities*

agricultural management plan (AMP): *any activity, procedure, or practice to prevent or remedy the introduction of agricultural chemicals into groundwater to the extent technically and economically practical adopted as a rule* *tor, defoliant, or desiccant"* (Colorado Revised Statutes, 1990. Definitions).

Commercial fertilizers are defined as *"fertilizer, mixed fertilizer, or any other substance containing one or more essential available plant nutrients which is used for its plant nutrient content and which is designed for use and has value in promoting plant growth. It does not include untreated animal and untreated vegetable manures, untreated peat moss, and untreated peat humus, soil conditioners, plant amendments, agricultural liming materials, gypsum, and other products exempted by regulation of the commissioner"* (Colorado Revised Statutes, 1971. Definitions).

The goal of the Groundwater Protection Program is to reduce negative impacts to groundwater and the environment by improving the management of agricultural chemicals…

Best Management Practices for fertilizer application and irrigation are essential components to protect groundwater.

The goal of the Groundwater Protection Program is to reduce negative impacts to groundwater and the environment by improving the management of agricultural chemicals and to assure that groundwater remains safe for domestic and livestock consumption by preventing contamination. A voluntary approach is emphasized, using education and training to achieve the goal. The legislative act creating the Agricultural Chemicals and Groundwater Protection Program gives the CDA authority to develop best management practices, which are defined as *"any voluntary activity, procedure, or practice…to prevent or remedy the introduction of agricultural chemicals into groundwater to the extent technically and economically practical"* (Colorado Revised Statutes, 1990. Definitions).

A three-tiered response is specified to address potential and actual groundwater pollution due to agricultural chemicals. **The first level of response** is preventive. These efforts include:

- Education and training in voluntary BMP implementation
- Establishment of voluntary BMPs appropriate to local conditions and type of agriculture
- Implementation of mandatory rules for agricultural chemical facilities with bulk storage and mixing/loading areas that exceed minimum thresholds
- Establishment of a statewide groundwater monitoring program and an aquifer vulnerability assessment analysis

The second level of response is mandated management practices. If prevention efforts fail to remedy a groundwater pollution problem, the Commissioner of Agriculture has the authority to designate AMAs and/or require the use of AMPs. An AMA is a designated geographic area defined by the Commissioner where there is a significant risk of groundwater contamination or pollution from agricultural activities.

An AMP is any activity, procedure, or practice adopted as rule, rather than implemented on a voluntary basis, to prevent or remedy the introduction of agricultural chemicals into groundwater to the extent technically and economically practical. This procedure essentially replaces voluntary BMPs with mandated BMPs in these geographic areas.

A third level of response is specified if continued groundwater monitoring reveals that designated AMAs and/or AMPs are not preventing or mitigating the presence of agricultural chemicals. At this level, the Commissioner and the Water Quality Control Commission confer and determine the appropriate regulatory response. The Water Quality Control Commission has final authority over the content of any promulgated control regulation.

As of this report's publication, the declaration of an AMA or AMP has not been deemed necessary by any of the seven Colorado Commissioners of Agriculture in office since the Groundwater Protection Program's inception in 1990. Nor has there been a recommendation for an AMA or AMP from Groundwater Protection Program staff, the Program's Advisory Committee, the Water Quality Control Commission, or the general public. In the early stages of the program, too little groundwater data was available to evaluate the need for these management tools. As groundwater data was collected and isolated areas of contamination identified, the program staff and Advisory Committee felt that voluntary BMP adoption had not been given sufficient time to diffuse within the agricultural community. Potential future use of these regulatory mechanisms will depend upon BMP adoption by agricultural chemical users and the results of the groundwater monitoring program.

There are three state agencies responsible for implementing the Agricultural Chemicals and Groundwater Protection Program:

- **Colorado Department of Agriculture** has overall responsibility for the Groundwater Protection Program. The CDA enforces rules for bulk storage and mixing/loading of agricultural chemicals, monitors the quality of the state's groundwater, and designates AMAs and AMPs if necessary.
- **Colorado State University Extension** provides education and training in methods designed to reduce groundwater contamination from agricultural chemicals.
- **Colorado Department of Public Health and Environment (CDPHE)** analyzes and interprets data, and writes reports.

These three agencies rely on a 13-member advisory committee to provide input from the agricultural community and the general public. Several groups with agricultural interests are represented, including pesticide applicators, agricultural chemical suppliers, agricultural producers, the green industry, the general public, and the Water Quality Control Commission. Committee members are approved by the Colorado Agricultural Commission and serve three-year terms.

The advisory committee meets annually or as needed to provide direction by helping to set educational and monitoring priorities; reviewing BMP feasibility, providing ideas on the most effective means of reaching intended audiences, and giving input on many other programmatic initiatives. This committee also helps draft policy and regulation when necessary. In 1991, a subcommittee was formed to draft the rules pertaining to bulk chemical storage and mixing/loading facilities. They were presented to the full committee before public hearings were conducted. In 2004, the committee helped introduce legislation regarding the Groundwater Protection Program's fee structure. The advisory committee's assistance and efforts were and continue to be invaluable.

Cooperation with Other Agencies

The Agricultural Chemicals and Groundwater Protection Program is only one facet of the state's overall groundwater protection strategy. Statutory authority for protecting the waters of the state, both surface water and groundwater, is primarily vested in the CDPHE's Colorado Water Quality Control Commission and the Water Quality Control Division. However, there are a number of local, state, and federal agencies and other organizations in Colorado that have a mandate to protect water resources. The intent of the Agricultural Chemicals and Groundwater Protection Program and the implementing agencies is to fulfill one aspect of water quality management in the context of a much larger network. The Groundwater Protection Program has ongoing collaborations with many agencies and organizations in Colorado. The USDA Natural Resources Conservation Service (NRCS), the USDA Agricultural Research Service (ARS), and the Colorado Agricultural Experiment Stations (AES) are heavily involved in the development of BMPs, as are various conservation districts and water conservancy districts. The state nonpoint source program fostered coordinated education efforts and demonstration projects, many with a mission complementary to the Groundwater Protection Program.

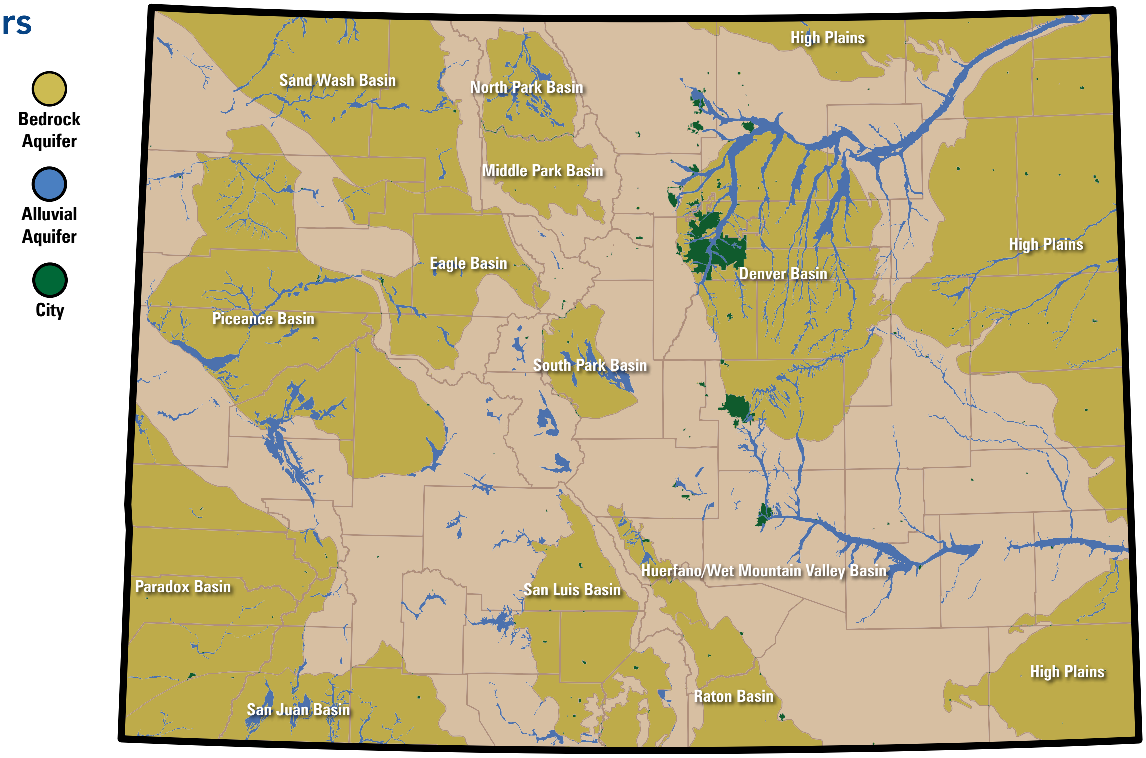
Monitoring efforts have been augmented

BMP cooperative demonstration site

Groundwater Protection Program Advisory Committee, approved by the Colorado Agricultural Commission, represents groups with ag-related interests and provides input to the program (February 2008).

Fortunately, the majority of groundwater wells sampled thus far is not contaminated by pesticides or fertilizers at levels deemed unsafe for humans by the EPA.

Colorado Aquifers



with cooperation from the Office of the State Engineer, the U.S. Geological Survey (USGS), and various groundwater management districts, water conservancy districts, and conservation districts throughout the state. Additionally, agricultural organizations such as Colorado Corn Growers, Colorado Livestock Association, Farm Bureau, Rocky Mountain Agribusiness Association and others cooperate with the Groundwater Protection Program to advance the goal of protecting Colorado's water resources.

Report Overview

This report summarizes since inception, the implementation of the Agricultural Chemicals and Groundwater Protection Program and is intended to provide an overview of activities and data. The monitoring program has prioritized its sampling in areas where agriculture predominates and rural homes utilize groundwater. These data form the backbone of the Groundwater Protection Program, as they determine the need and priority for education and other program resources. The program has completed sampling of groundwater systems in the following regions of Colorado:

- South Platte River Basin
- San Luis Valley
- Arkansas River Basin
- Front Range Urban
- High Plains
- West Slope (Western Colorado)
- North Park
- Wet Mountain Valley
- Gilpin County

Groundwater protection remains a state priority, and agricultural chemical use is still prevalent. Monitoring data, assessing vulnerability, and surveying chemical use data indicate areas where water quality still is susceptible to contamination. Fortunately, the majority of groundwater wells sampled thus far are not contaminated by pesticides or fertilizers at levels deemed unsafe for humans by the EPA. Continued cooperation from crop producers, agricultural chemical applicators, and homeowners is critical to ensure adequate groundwater quality for generations to come.

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The Colorado Department of Agriculture serves as the lead agency for the Groundwater Protection Program.

The administration of this program is a multi-agency effort that involves the CDA partnering with CSUE and the CDPHE. The CDA's responsibilities are to:

1. Coordinate efforts among the three agencies
2. Regulate agricultural chemical bulk storage and mixing/loading
3. Monitor the quality of Colorado's groundwater resources
4. Perform analyses of groundwater samples at the CDA Standards Laboratory
5. Assess the vulnerability of Colorado's groundwater to contamination from agricultural chemicals
6. Oversee the program's budget

Regulation of Agricultural Chemical Bulk Storage and Mixing/Loading Facilities

The Commissioner promulgated rules for facilities where pesticides and/or fertilizers are stored and handled in quantities that exceed minimum thresholds. The purpose of the rules is to prevent and/or contain spills and leaks that can potentially contaminate groundwater resources. The rules establish standards for the construction and operation of bulk liquid and dry storage facilities and mixing/loading areas.

The rules also require bulk storage and mixing/loading facility designs to be:

1. Signed and sealed by an engineer registered in the state of Colorado, or
2. From a Commissioner-approved source and available for public use.

To meet the latter requirement, the CDA and CSUE produced a free set of design plans, *Plans for Small To Medium-Sized Agricultural Chemical Bulk Storage & Mix/Load Facilities* (CSUE and CDA, 2012). Copies of the complete storage and mixing/loading rules, *8 CCR 1206-1 Water Quality Control Concerning Agricultural Chemicals and Ground Water* (CDA 2011) and a summary folder, *Rules Summary For Bulk Agricultural Chemical Storage Facilities and Mixing/Loading Areas* (CDA 2012) are available from the CDA.

Liquid fertilizer storage facility

The Commissioner is authorized to enforce these rules. Through various investigative powers, the Commissioner has the authority to issue cease and desist orders and impose civil penalties up to $1,000 per day, per violation.

The CDA employs field inspectors throughout the state who, among other duties, enforce the bulk storage and mixing/loading rules. Facilities are also visited to provide information and answer specific questions regarding these rules. This educational process provides assistance to determine whether compliance with the rules is required, and what specifically must be accomplished to comply with the required rules.

Bulk pesticide storage facility inspections began Sept. 30, 1997, and bulk fertilizer storage facility inspections began Sept. 30, 1999. More than 1,800 inspections have been performed at facilities throughout the state. Although many facilities had minor problems requiring correction, inspections have resulted in a 97% compliance rate, based on the small number of cease and desist orders and violation notices issued. As this part of the Groundwater Protection Program moves forward, focus has shifted toward maintenance issues at existing facilities rather than construction of new facilities, which was common at the onset of the program.

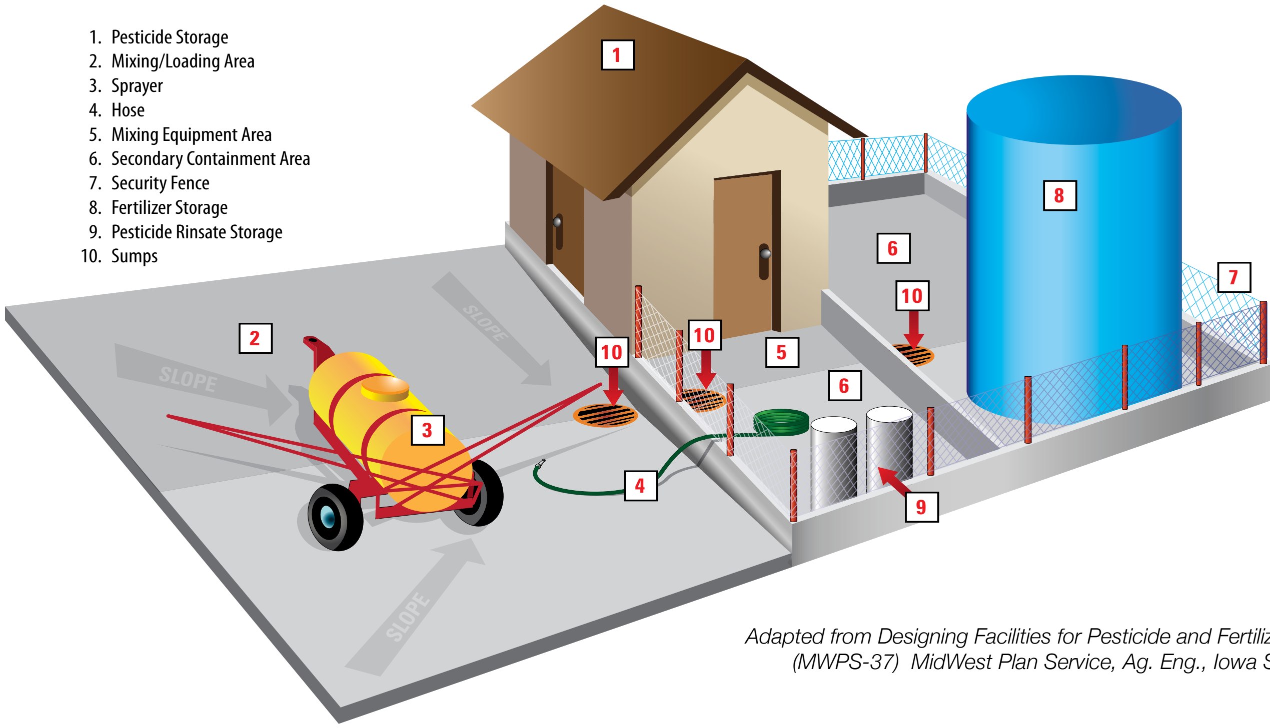
Pesticide Waste Collection Program

In 1995, a pilot pesticide waste collection program debuted in Adams, Larimer, Boulder, and Weld counties. Its purpose was to provide pesticide users the opportunity to dispose of banned, canceled, or unwanted pesticides in an economically and environmentally sound manner. Part of the program funding was provided by an EPA Clean Water Act Section 319 grant. The program was a success with approximately 17,000 pounds of waste pesticides from 67 participants collected and safely disposed of.

Based on the pilot program's success, CDA was asked to continue the program in other areas of the state. However, the CDA had no statutory authority or funding to operate such a program. Two alternatives were discussed to continue a pesticide waste collection program: the CDA could seek statutory authority and funding from the legislature to operate a state-run program, or the CDA could attempt to implement a private program operated by a hazardous waste handling company.

The CDA contacted hazardous waste contractors to determine their level of interest in creating a private pesticide waste collection and disposal program. One compa-

Pesticide and Fertilizer Storage/Mixing Facility



Adapted from Designing Facilities for Pesticide and Fertilizer Containment, (MWPS-37) MidWest Plan Service, Ag. Eng., Iowa State Univ. 1991.

ny, MSE Environmental, Inc., indicated interest and upon discussions, the private program was pursued, mainly because a state program required enabling legislation. After numerous issues were addressed, MSE Environmental, Inc. targeted the San Luis Valley and six northeastern Colorado counties. Registration opened in early 1997 and MSE collected more than 10,500 pounds of pesticide waste from 33 participants. Based on the program's success, MSE conducted a statewide collection program in November 1997, and collected more than 23,000 pounds from 42 participants. The waste collection program continued as described until 2010. The accompanying figure provides a summary of the collection results.

The CDA currently facilitates a pesticide waste collection program by hosting a website (http://www.colorado.gov/ag/pw) for parties interested in disposing of pesticide waste.

Colorado's Pesticide Management Plan and Groundwater Sensitivity/Vulnerability Mapping

In October 1991, the EPA released "Pesticides and Groundwater Strategy," which describes the policies, management programs, and regulatory approaches the EPA will use to protect the nation's groundwater resources from the risk of pesticide contamination. The strategy emphasizes prevention over remedial treatment. The centerpiece of the strategy was the development and implementation of state pesticide management plans (PMPs) for pesticides that pose a significant risk to groundwater resources (EPA, 1991).

The EPA published the proposed rule June 26, 1996 (EPA, 1996). Colorado submitted a complete draft of its generic PMP to the EPA for informal review in 1996. After multiple revisions based on comments received, Colorado submitted a final version with which the EPA concurred in March 2000 (Yergert and others, 2000). Six years later, the EPA eliminated the PMP rule, but still encourages states to produce generic PMPs and continue groundwater protection programs. Colorado plans to continue to use its PMP for program guidance.

One significant result for Colorado: The EPA required a sensitivity analysis and assessment map in Geographic Information System (GIS) format. The map was used to determine where to focus education and monitoring activities.

Year	lbs Collected	# Participants
1995	17,000	67
1997	33,500	75
1999	19,792	47
2001	13,486	34
2002	8,762	33
2003	2,254	7
2004	8,520	10
2005	5,023	11
2007	46,007	7
2008	31,099	9
2009	63,038	8
2010	38,415	5
Total	**286,896**	**313**

Pesticide Waste Collection Program

A small EPA grant paid for a sensitivity analysis pilot project in northeastern Colorado, which was completed and submitted in 1996. The EPA reacted favorably and provided money for a statewide sensitivity analysis, finished in 1998.

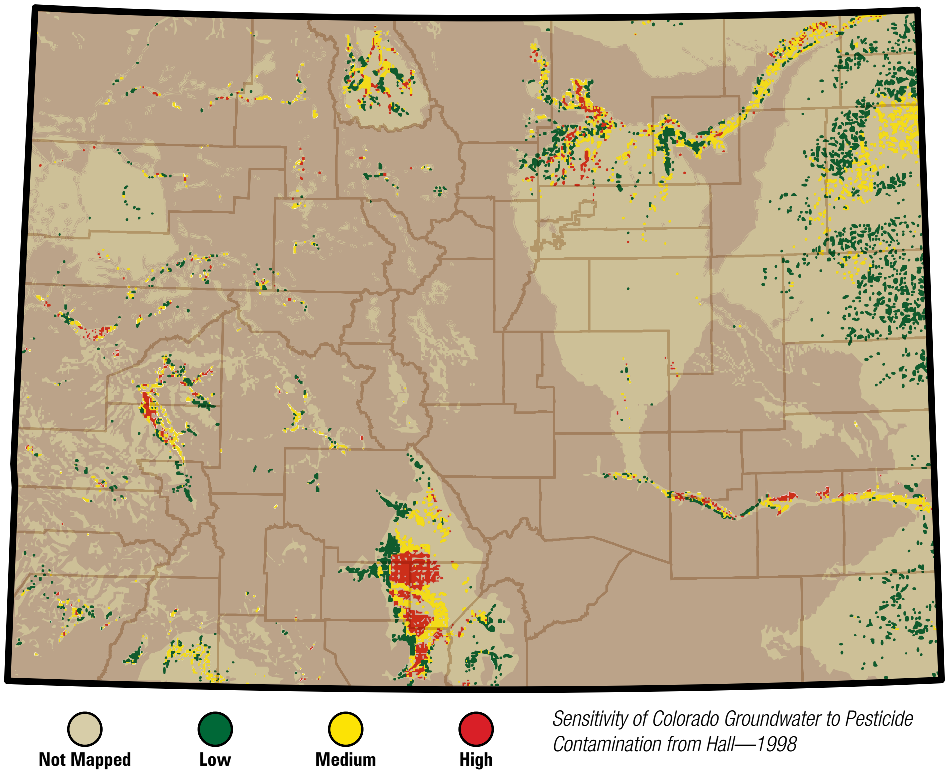
The Groundwater Protection Program used the information to publish an eight-page fact sheet, "Relative Sensitivity of Colorado Groundwater to Pesticide Impact." The publication assesses aquifer sensitivity based on conductivity of exposed aquifers, depth to water table, permeability of materials overlying aquifers, and availability of recharge for transport of contaminants. The factors incorporated the best statewide data available and the important aspects of Colorado's unique climate and geology (Hall, 1998).

In 1999, the Groundwater Protection Program received spending authority to begin an aquifer vulnerability project to complement and improve the existing aquifer sensitivity maps. One project was completed in 2001 with the Colorado School of Mines (Schlosser and others, 2000; Murray and others, 2000). Another, "Probability of Detecting Atrazine/Desethyl-atrazine and Elevated Concentrations of Nitrate in Ground Water in Colorado," was done in conjunction with USGS and completed in 2002 (Rupert, 2003).

Using GIS resources and expertise gained by developing the maps, the Groundwater Protection Program created a statewide nitrate vulnerability map in 2001. A Colorado State University master of science project produced the map and an accompanying field-scale nitrate leaching index (Ceplecha, 2001; Ceplecha and others, 2004).

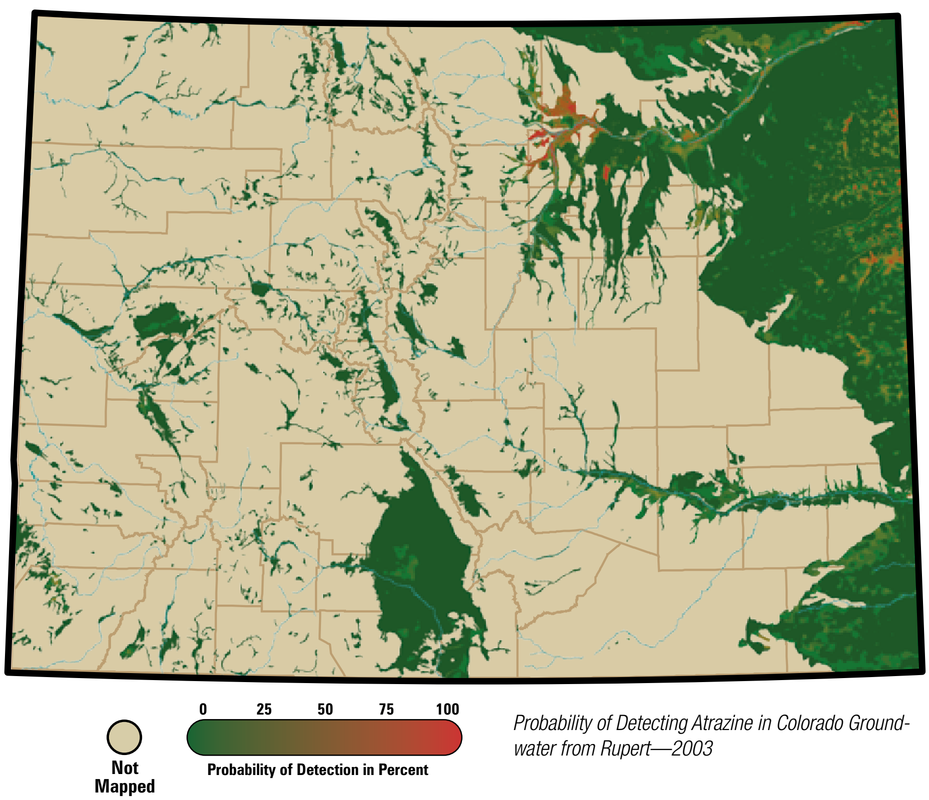
These groundwater mapping projects improved the program's ability to focus resources on areas with the greatest potential for contamination. The program continues to refine and update the groundwater sensitivity and vulnerability maps as better data and resources become available.

Pesticide Sensitivity



Sensitivity of Colorado Groundwater to Pesticide Contamination from Hall—1998

Probability of Detecting Atrazine

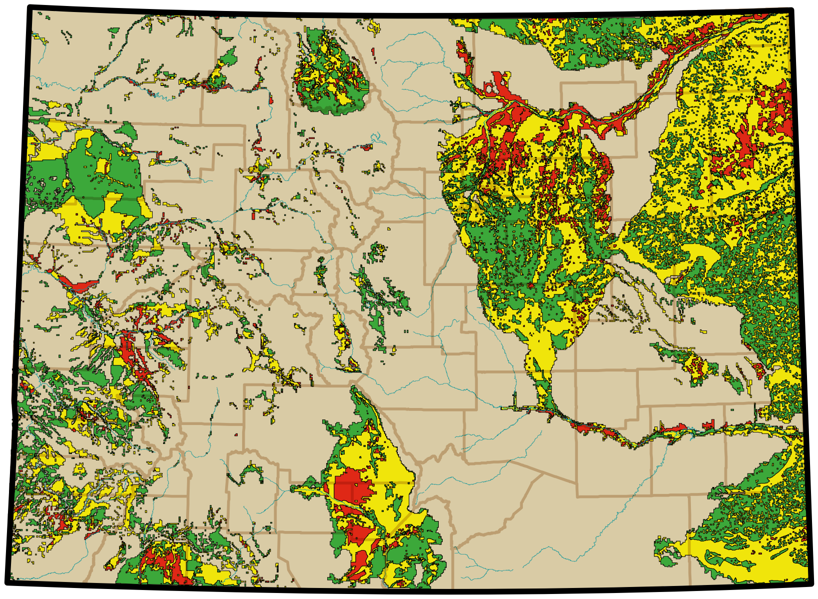


Probability of Detecting Atrazine in Colorado Groundwater from Rupert—2003

aquifer sensitivity: *the relative ease with which a pesticide or nitrate can migrate to groundwater. It is largely a function of the physical characteristics of the overlying area and potential recharge (precipitation and irrigation)*

aquifer vulnerability: *combines aquifer sensitivity as well as land use, management, and pesticide properties*

Nitrate Vulnerability



Vulnerability of Colorado Groundwater to Nitrate Contamination from Ceplecha—2001

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Ceplecha, Z.L., R.M. Waskom, T.A. Bauder, J.L. Sharkoff and R. Khosla. 2004. "Vulnerability assessments of Colorado groundwater to nitrate contamination." Water, Air, and Soil Pollution 159 (1): 373-394.

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Schlosser, S.A., J.E. McCray, and R.M. Waskom. 2000. "The effect of variations in hydrogeologic and physicochemical transport properties on the model-predicted vulnerability of Colorado groundwater to pesticides." GSA Abstracts Vol. 32, No. 5:A-37.

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Yergert, M., R. Wawrzynski, R. Waskom, and B. Austin. 2000. Generic Groundwater Pesticide Management Plan. Colorado Department of Agriculture.

The groundwater monitoring program's purpose is to evaluate possible impacts to groundwater quality from current and past use of agricultural chemicals and provide accurate data to:

- Determine if agricultural chemicals are present
- Determine if trends in water quality exist
- Provide monitoring data to help the Commissioner of Agriculture identify potential agricultural management areas
- Evaluate the effectiveness of BMPs
- Assess groundwater vulnerability

Groundwater Monitoring

Monitoring has been prioritized in areas where agriculture is the predominate land use. The Groundwater Protection Program (Program) has collected data through the initial sampling of groundwater systems in the largest agricultural and urban regions of Colorado. The data forms the backbone of the Program and determines the need and priority for education and other program resources around the state. This monitoring program, which involves sample collection and lab analysis, is the first statewide effort to establish the potential impacts and magnitude of agricultural chemical (agrichemical) contamination. A map of the study areas and sample locations is provided on page 15. As of December 2011, the monitoring program has sampled 1,246 wells and analyzed 2,694 samples throughout Colorado.

Monitoring data, vulnerability assessments, and chemical user survey data indicate there are areas in Colorado where water quality is susceptible to contamination. Fortunately, the majority of wells sampled thus far are not contaminated at levels deemed unsafe for humans by the EPA.

Monitoring Approaches

The Program has historically utilized several approaches to monitoring. While these different approaches will be explained in more detail below, the general objective has been to determine baseline water quality data in areas not previously studied. The data are then used along with supplemental information about location-specific nonpoint contaminant sources, agrichemical use characteristics, and agricultural practices to determine the need for a dedicated monitoring network for long-term monitoring.

Two key monitoring approaches used by the program are reconnaissance surveys and dedicated monitoring. Either of these approaches can be implemented on a regional or sub-regional area through the program's own initiative or through a request made by another entity about a specific groundwater quality concern. Generally, any area not previously sampled falls under a reconnaissance survey, while areas with networks established for the purpose of continued monitoring after a reconnaissance survey fall under dedicated monitoring.

Regional area, as defined by the program, is a large area that may cover multiple watersheds, counties, or other political boundaries within Colorado. The hydrogeology, geography, agricultural practices, and population density—hence the potential for groundwater quality impact—may vary widely throughout a regional area. Most times the program defines a regional area as a particular river drainage basin and its associated alluvial aquifer (i.e. South Platte River Basin), or as a major regional aquifer (i.e. High Plains Sedimentary Rock Aquifer). Other considerations for a regional area may be geographically significant areas within the state like Front Range, West Slope, or a major groundwater basin. **A sub-regional area** is a smaller area within a larger regional area. A tributary basin or individual county may constitute a sub-regional area. Sampling of sub-regional areas may occur after the sampling of a regional area as

Groundwater monitoring equipment at well site

Program technicians utilize standardized and approved equipment and techniques for collection of groundwater samples.

part of an attempt to target areas of known contamination for more in depth reconnaissance or dedicated monitoring. However, a single county or other small area may also be sampled completely independently from any regional reconnaissance work as part of a request made by an external entity, such as a county health department.

Reconnaissance surveys produce a preliminary assessment of groundwater quality in an area of interest to decide whether additional investigation into groundwater quality is warranted. For the most part, the Program attempts to sample wells that are already in-

Collection of representative groundwater data is dependent on being organized in the field and keeping sampling equipment clean and functioning properly.

The Program's laboratory utilizes state-of-the-art instrumentation for analysis of agricultural chemicals in groundwater samples.

> The Groundwater Protection Program has collected over 2,600 samples from more than 1,200 wells throughout Colorado. This extensive dataset is available to query online at www.colorado.gov/ag/db or through the CSU water quality website, www.csuwater.info.

stalled and currently in use by the well owner. Usually such wells are used for domestic, stock, or irrigation purposes. These different well types are those most frequently used for reconnaissance work.

The number of samples collected in a reconnaissance survey is mostly dependent on the size of the area being sampled, the water quality parameters to be measured (cost of laboratory analysis), and the Program's resource and budget constraints. When possible, locations are selected randomly, but access and owner consent dictates the final locations. Unusual or inconsistent results discovered during initial sampling in a reconnaissance survey may warrant follow-up sampling. Follow-up sampling is still considered part of the reconnaissance survey work in an area, but usually consists of re-sampling specific wells or increasing sample density within a smaller area (sub-regional area) to determine both the validity and extent of groundwater contamination discovered during reconnaissance survey work in a larger regional area.

If reconnaissance survey work turns up areas warranting further monitoring efforts due to groundwater being contaminated with agrichemicals, then the program will establish a dedicated monitoring network for the regional or sub-regional area of interest. For this type of monitoring the program prefers to use dedicated monitoring wells, but other well types may be used. Preferably, the wells used for the dedicated monitoring should be permanent, thoroughly understood with regard to well construction and placement within the aquifer, and easily and readily accessible by program personnel. Wells designated for 'Quality Monitoring' are the best wells for dedicated monitoring, because they usually have negligible changes between sampling events, whereas a domestic or irrigation well owner may conduct maintenance on their well that may impact sample quality consistency between sampling events.

The Program may strategically use multiple well types in an area to monitor different depths in the aquifer being studied. Monitoring wells of primary interest to the Program are installed at the top of the water table and have short screened intervals that allow sampling of a discreet location in the aquifer. Domestic wells tend to have longer screened intervals installed deep within the saturated thickness of the aquifer to ensure ample supply well into the future for the well owner. Flow rates from domestic wells are statutorily limited to 15 gpm, which is significantly higher than the typical 0.10 gpm flow rate used during sampling of monitoring wells. In stark contrast, irrigation wells have large diameter (eight inches or more) boreholes with screened intervals that can sometimes span the entire saturated thickness of an aquifer. Withdrawal rates range from less than 100 gpm to more than 2,000 gpm in these wells.

Samples from monitoring wells sampled by the Program are interpreted to represent the most recent contamination to an aquifer and therefore the most recently recharged water. Domestic wells can represent various depths in an aquifer but tend to be installed deeper in the aquifer and therefore represent older water and, when encountered, contamination that impacted the aquifer many years earlier. Because of the high withdrawal rates and screened interval length of irrigation wells, sample results from these wells are usually interpreted as an average quality for groundwater within immediate vicinity to the well because of the mixing of water from various depths in the aquifer and from up to a quarter mile away.

Study Area Selection

Factors considered in the choice of study areas for groundwater monitoring include:

1. Significant use of agricultural chemicals and the potential for chemical migration into groundwater supplies
2. Groundwater in a major alluvial aquifer or shallow unconfined aquifer, or a significant portion of the groundwater is shallow

3. Significant portion irrigated by either surface water diversions or groundwater pumping
4. Soil types conducive to leaching, or soil that drains easily
5. Alluvial and/or shallow bedrock aquifers used as domestic water supplies
6. Areas currently included in other water quality monitoring studies

The Program informs interested groups in selected study areas and closely coordinates with federal agencies, county extension, conservancy districts, and local health and water officials.

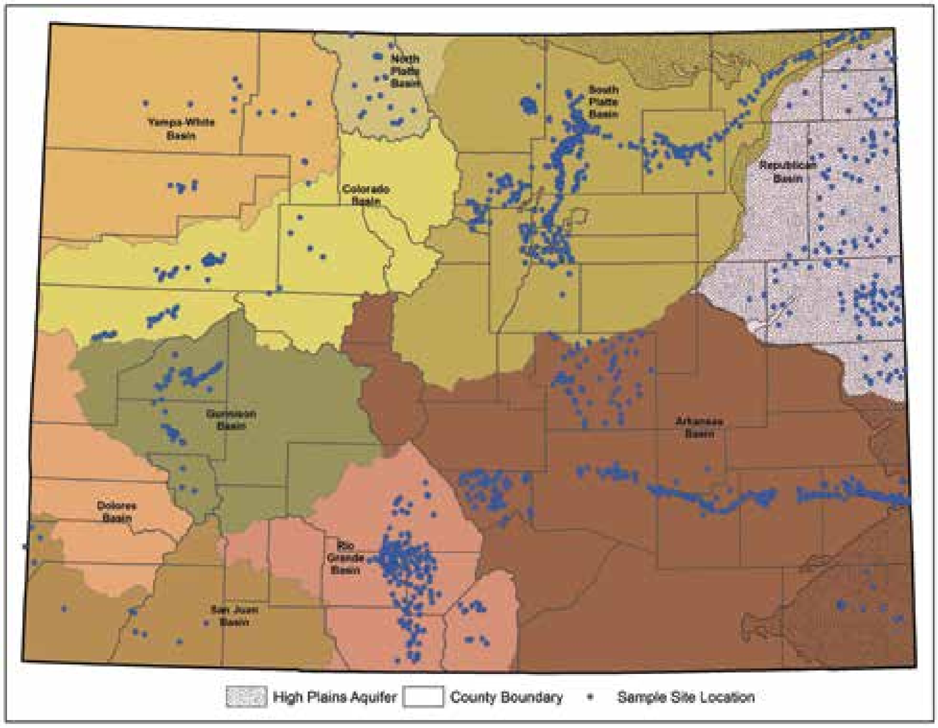
Well Selection

When the Program decides to use existing wells for studying specific parts of the aquifer in a particular study area, the following preferences are evaluated when determining the well type to use and placement within the study area:

- Low flow, shallow depth
- Location in the target aquifer or a connecting branch
- Location within or down-gradient of agricultural practices
- Groundwater depth of no more than 150 feet and generally less than 50 (except in unconfined, deep formations like the Ogallala Aquifer in the High Plains where depths can reach 200 feet)
- Installed pump in working order
- Known direction of groundwater flow
- Wellhead and casing in good physical condition and documentation available
- Wellhead area free of point sources of contamination
- Well owner cooperation

Not every preference is met in the selection of one well or another, but effort is made to cover as many as possible.

Groundwater Monitoring Locations



Drinking Water Standards

Under the authority of the Safe Drinking Water Act (SDWA), the EPA sets standards for approximately 90 contaminants in drinking water, of these 22 are pesticides. For each one, the EPA sets a legal limit, or maximum contaminant level (MCL). Water that meets these standards is considered safe to drink, although people with severely compromised immune systems and children may have special needs. Public water suppliers may not provide water that doesn't meet these standards. In most cases, EPA delegates responsibility for implementing drinking water standards to states and tribes. Private well owners are responsible for ensuring their well water is safe to drink (Environmental Protection Agency, 2008).

Sample Collection and Analysis

Program personnel typically sample wells between May and October. The samples can be analyzed for basic water quality ions, selected pesticides, dissolved metals, and other parameters pertinent to monitoring for agrichemical contamination that may be important in a particular groundwater system. The number of analyses a sample undergoes is dependent on the type of monitoring approach being implemented, as it is costly to have all constituents analyzed of every sample collected. Detailed information on sample collection protocol is in Appendix II.

The Program has utilized lab services from cooperating agencies (CSU, CDPHE, CDA), and from external labs (Montana Department of Agriculture, USGS, and the University of Colorado's Center for Environmental Mass Spectrometry) since groundwater sampling began in 1992. The CSU Soil, Water, and Plant Testing Lab has also been used when necessary to perform routine analysis for nitrate, basic inorganic compounds, or dissolved metals. After using the CDPHE lab in 1992 and 1993, the Program leveraged U.S. EPA funding to purchase the necessary instrumentation to establish CDA's Biochemistry Lab in 1994. At the time of this revision, the lab analyzes for nitrate, nitrite, and a suite of 95 pesticide and pesticide breakdown compounds using several methods that include gas chromatography, liquid chromatography, mass spectrometry, and ion chromatography (Appendix III).

The Program employs one full-time chemist and one part-time chemist to run the lab. Employing program-specific chemists has created flexibility to analyze for pesticides that have potential for groundwater contamination specific to Colorado conditions and agrichemical use patterns. A list of the analyzed substances, laboratory analysis methods, protocol, instrumentation, and typical reporting limits are in Appendix III.

The maximum level of nitrate in drinking water allowed by the EPA is 10 ppm nitrate-nitrogen (NO_3-N). Pesticide MCLs vary widely. For example, the drinking water standard for the herbicide atrazine is three ppb, but the standard for the insecticide lindane is 0.2 ppb. Most pesticides do not currently have established EPA drinking water standards (Environmental Protection Agency, 2009).

Monitoring Program Study Areas 1992-2011

The study areas sampled for water quality can be organized into three types of aquifers according to the Colorado Geological Survey: major alluvial aquifers, major sedimentary aquifers, or igneous/crystalline bedrock aquifers. Given the different monitoring approaches used by the Program, it is possible that a sampling effort in a regional or sub-regional area may involve more than one aquifer type. However, the Program usually conducts sampling efforts on a particular aquifer type within a regional or sub-regional area mostly to ensure accurate application of findings to the correct aquifer type. The following list shows study areas delineated by the Program at regional or sub-regional scale, the type(s) of aquifer evaluated, and the general geographic area involved:

- South Platte River Basin
  - Regional Reconnaissance—1992, 1993—South Platte River alluvial aquifer domestic well network from Denver to Julesburg, and a follow-up confirmation sampling of domestic wells in Morgan and Sedgwick Counties
  - Sub-regional Dedicated Monitoring, Weld County—1995 to present—South Platte River alluvial aquifer domestic, irrigation, and monitoring well networks from Brighton to Pierce, north of Greeley in Weld County
  - Regional Dedicated Monitoring, Lower South Platte—2001, 2008, 2010—South Platte River alluvial aquifer monitoring well network from just east of Wiggins to Julesburg
- San Luis Valley
  - Regional Reconnaissance—1993—Domestic well network within the unconfined portion of tertiary-quaternary basin-fill aquifer of the Rio Grande River Basin
  - Regional Dedicated Monitoring—1993, 2000, 2007—USGS monitoring well network within the unconfined portion of the basin-fill aquifer from just north of Center to near La Jara and east to Blanca
  - Regional Dedicated Monitoring—2009, 2011—Domestic well network within the unconfined portion of the basin-fill aquifer from Saguache south to Antonito and east to Blanca
- Arkansas River Basin
  - Regional Reconnaissance—1994, 1995—Arkansas River alluvial aquifer domestic and irrigation well network extending from Pueblo east to Holly
  - Regional Dedicated Monitoring—2004, 2005, 2008, 2010—Arkansas River and major tributary alluvial aquifer monitoring well network extending from Pueblo east to Holly
  - Sub-regional Reconnaissance, El Paso County—2006—Domestic well network within alluvial aquifer of Fountain, Jimmy Camp, and Upper Black Squirrel creeks and shallow Upper Dawson sedimentary aquifer of the Denver Basin in El Paso County
- Front Range Urban
  - Regional Reconnaissance—1996—Domestic and monitoring well network within or near urban development in various alluvial aquifers of the South Platte River, Arkansas River and major tributaries extending from Fort Collins south to Pueblo
  - Regional Dedicated Monitoring—2005, 2007, 2008, 2010—Monitoring well network within developed urban land along the Front Range—South Platte River and major tributary alluvial aquifer from Fort Collins to Castle Rock and Arkansas River and major tributary alluvial aquifer from Colorado Springs to Pueblo
- High Plains
  - Regional Reconnaissance—1997—Domestic and irrigation well network within unconsolidated to semi-consolidated sands, gravels, clays, and silts of the Miocene-aged Ogallala Formation sedimentary aquifer extending from the northeast corner to the southeast corner of Colorado's eastern plains
  - Regional Dedicated Monitoring—2008, 2011—Monitoring well network established in the Ogallala Formation extending from just north of Holyoke to south of Burlington
- West Slope (Western Colorado)

- ◦ Regional Reconnaissance—1998, 2000—Domestic and irrigation well network within alluvial quaternary aquifers of the Colorado, Gunnison, Uncompahgre, San Juan, Dolores, Yampa, and White Rivers extending from near Craig in the north to near Durango in the south
  - ◦ Sub-regional Reconnaissance, Tri-Rivers—2009—Domestic well network within alluvial quaternary aquifer of the Colorado, Gunnison, Uncompahgre, and major tributaries along the I-70 corridor from Newcastle to Grand Junction, from Delta east to Paonia, and south of Montrose
- North Park Basin
  - ◦ Regional Reconnaissance—2000—Domestic and stock well network established in the unconfined tertiary Coalmont Formation aquifer of Jackson County
- Wet Mountain Valley
  - ◦ Regional Reconnaissance—2002—Domestic well network within quaternary alluvium and tertiary valley-fill deposit aquifer of Custer County
- Mountainous Region
  - ◦ Sub-Regional Reconnaissance, Gilpin County—2005—Domestic well network established in Precambrian crystalline fractured rock aquifer in Colorado's mountainous region

South Platte River Basin

Study Area Description

The South Platte River Basin drains an 18,924 square mile area comprising the northeastern quarter of Colorado and consists of mountain, urban, agricultural, and rangeland settings. There is a 4,000 square mile alluvial aquifer system of Pleistocene alluvial and eolian deposits that lays alongside the main stem of the South Platte River and its major tributaries. Moving east from the hogback in the foothills to the eastern plains along the main South

South Platte River, Kersey

Platte stem and its tributaries, alluvial deposits range from thicknesses of less than a foot to more than 290 feet in some areas and form a continuous unconfined aquifer that is in hydraulic connection with the river. This valley-fill aquifer is recharged by precipitation, applied irrigation water, and leakage from canals and reservoirs. The agricultural economy of the basin is based on irrigated and dry-land farming, as well as livestock production. An extensive area of irrigated agriculture containing coarse-textured soils, shallow water tables, and a variety of other land–use practices utilizing agrichemicals make this basin highly vulnerable to groundwater contamination.

The program has sampled this alluvial aquifer both with reconnaissance and dedicated monitoring approaches since 1992. Through the initial regional reconnaissance and subsequent sub-regional reconnaissance and dedicated monitoring efforts, groundwater quality has been thoroughly monitored to establish the possible effects and magnitude of agrichemical contamination. Due to the extent and sensitivity of the alluvial aquifer network, the majority of the program's efforts have been spent in the agricultural setting; however, sampling events in the urban setting (Front Range Urban) and the mountain setting (Gilpin County) have also been accomplished. These other sampling efforts have included sampling parts of the Upper Dawson sedimentary bedrock aquifer (part of the Denver Basin) and crystalline igneous bedrock aquifers, in addition to the valley-fill aquifers.

Regional Reconnaissance—1992, 1993

The area of sampling stretched from just north of Denver-metropolitan eastward to Julesburg near the Nebraska state line in Sedgwick County. A regional sampling of 96 domestic, stock, and irrigation wells initiated reconnaissance surveying in 1992. In 1993, a sub-regional sampling of 47 wells in Morgan and Sedgwick counties confirmed and further defined the extent of water quality impacts. Results of these sampling events showed more than 90% of sampled wells contained detectable concentrations of the nitrate ion. About 34% of wells sampled in 1992 and 38% sampled in 1993 contained concentrations of nitrate as nitrogen (NO_3-N) above the EPA drinking water standard of 10.0 ppm. One particular area in Weld County stretching from just north of Brighton to Greeley had several wells with NO_3-N greater than 20 ppm. A second area of elevated nitrate appeared around Wiggins in western Morgan County. Nitrate levels then decreased through eastern Morgan and Logan counties with few exceptions until levels increased again in Sedgwick County, with the overall average rising above the EPA drinking water standard.

Laboratory analysis for 37 different pesticide compounds revealed the detection of seven different pesticide compounds in 1992. Only nitrate was analyzed of samples collected in the 1993 follow-up sampling. About 65% of the wells contained no measurable pesticide levels. The herbicide atrazine was detected in seven wells (seven %) and one well contained the herbicide alachlor at 3.0 ppb, exceeding the EPA drinking water standard of 2.0 ppb.

Sugar beets are harvested in Weld County, against a backdrop of Meeker and Long's peaks.

Sub-regional Dedicated Monitoring
Weld County—1995 - Present

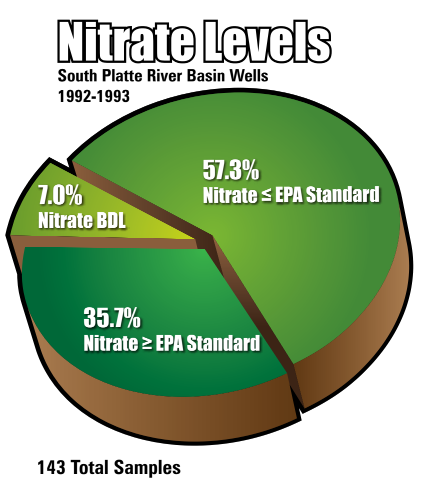
As a result of reconnaissance surveying detecting widespread, elevated nitrate levels and a high percentage of wells with pesticides, a long-term monitoring effort was initiated in 1995 in the South Platte alluvial aquifer from Brighton to north of Greeley. The goal for this dedicated monitoring effort was to examine trends in groundwater quality and help forecast the future effects of BMPs implemented in the area.

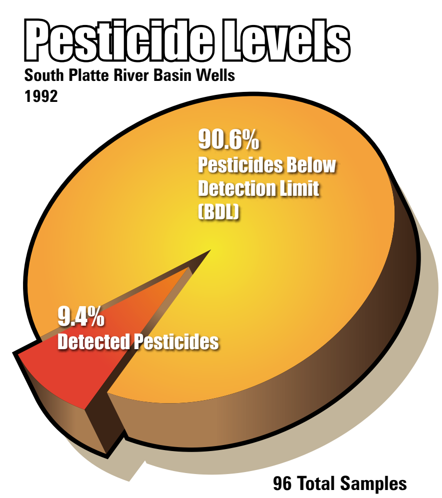
A variety of factors influenced the selection of Weld County for long-term monitoring: suitable networks of wells could be assembled from existing wells; the North Front Range Water Quality Planning Association (NFRWQPA) installed monitoring wells in the area in 1991, and had begun water quality testing in 1989 on a large set of the area's irrigation wells; and finally, local water quality interests were willing to cooperate.

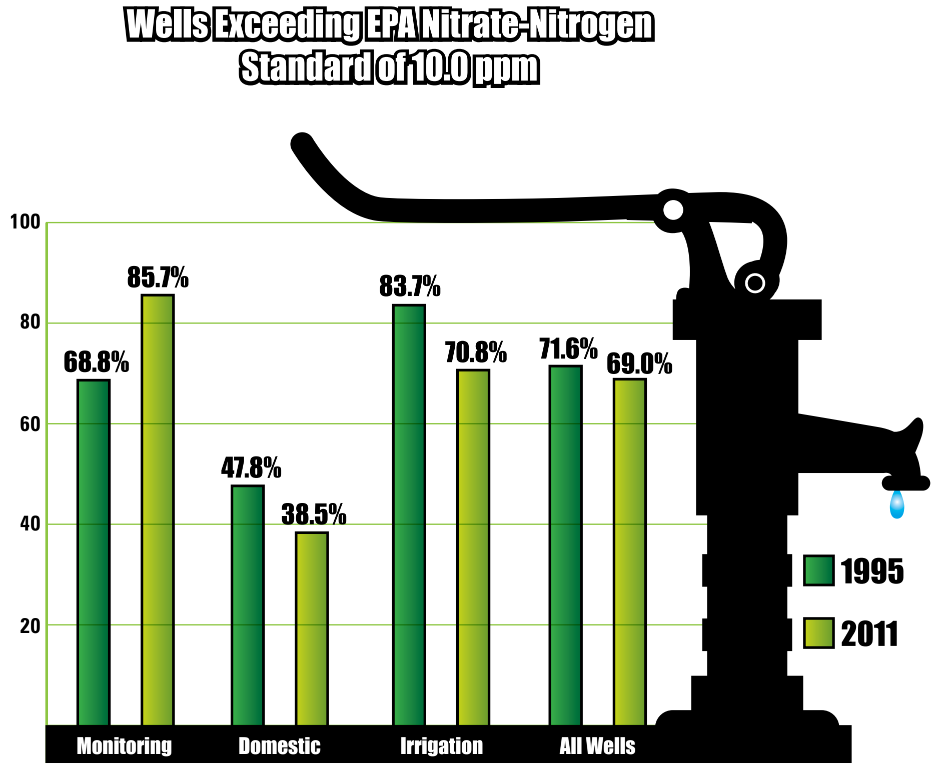
The original intent for the network was to sample three sets of distinct well types: 20 NFRWQPA monitoring wells now operated mostly by Central Colorado Water Conservancy District (CCWCD), 60 irrigation wells, and 23 domestic wells. Monitoring and irrigation wells would be sampled annually and domestic wells tri-annually starting in 1995. In 1995, all sampled wells would undergo full pesticide and nitrate analysis, then in 1996 monitoring and domestic wells would be analyzed for pesticide compounds in addition to nitrate, while irrigation wells would undergo an immunoassay screen for triazine herbicides in addition to nitrate. Due to a variety of reasons, well numbers within each network, the pesticide compounds screened for in each sample, and detection limits varied from year to year. Overall the trend has been an increase in the number of pesticide compounds analyzed for, a decrease in the detection limit of most compounds, and a decrease in the number of irrigation well samples since 1995.

In 2011, 21 monitoring wells, 24 irrigation wells, and 13 domestic wells were sampled. The impacts of a drought that occurred in the early 2000s coupled with changes to regulation of water rights has resulted in a curtailment of irrigation well pumping and management which affects the number of irrigation wells the program is able to sample in any given year. Ultimately, the Program decided to focus on sampling 36 of the most consistently available irrigation wells. Nonetheless, changes in well owner management, damage, and other conflicting issues have continued to prevent the Program from acquiring samples from this reduced number of wells. However, the domestic and monitoring well networks have been fairly consistent.

Keeping in mind the different interpretations of water quality that can occur due to the type of well used (Monitoring Approaches), the results from the first two years of dedicated monitoring showed median NO_3-N < 10 ppm for domestic wells, 20 ppm for monitoring wells, and slightly less than 20 ppm for irrigation wells. While both the monitoring and irrigation well networks had a similar number of wells over the EPA drinking water standard, the monitoring well network had about 50% of its wells over 20 ppm compared to only 38% of irrigation wells. Subsequent sampling events from the well networks have continued to show median NO_3-N concentrations hovering right around the concentrations seen in 1995 and 1996.







South Platte River Basin, Weld County, 1995 and 2011

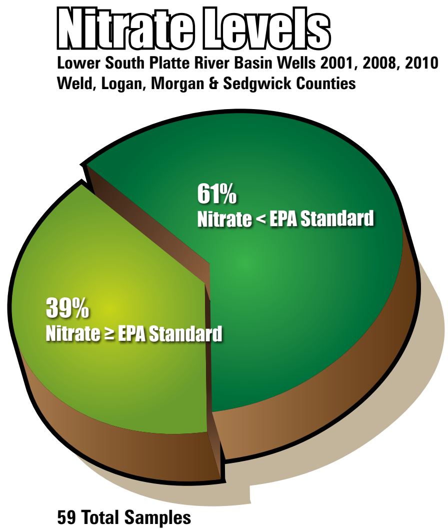
The monitoring well network has shown more year to year variability than the irrigation and domestic well networks. In 2011, median NO_3-N concentrations of 21.3, 16.7, and 9.1 ppm were reported for the monitoring, irrigation, and domestic well networks, respectively. The number of monitoring and irrigation wells with 20 ppm or more NO_3-N is nearly identical to what was discovered in 1995. While multiple individual wells in the monitoring and irrigation networks have statistically significant upward or downward NO_3-N concentration trends, each network as a whole shows no evidence toward a trend. And even for the wells with trends, no obvious patterns exist spatially (i.e., clusters of wells with a similar response). Due to the domestic wells only being sampled tri-annually until 2007, when they were then switched to annual sampling, there is insufficient data for conducting accurate long-term trend analysis as of 2011.

The initial 1995 laboratory analysis for 19 different pesticide compounds revealed 81% of all wells sampled having at least one pesticide compound detected. Of the 101 total detections in 71 of 88 sampled wells, 57% were of atrazine, 24% of prometon, and 17% of metolachlor. Domestic and irrigation wells had the greatest percentage of atrazine detections, and monitoring wells had the largest percentage of prometon detections. In 1996, the program initiated use of the immunoassay triazine herbicide screen for irrigation well samples. From 1996 to 2004, the Program had obtained sufficient data to show a statistically significant ($P<0.001$) decline of 50% in median triazine concentration. Fourteen individual irrigation wells showed a statistically significant decrease in concentration, 19 wells had no trend, and none showed an increase. Use of the immunoassay ceased in 2004 when the manufacturer changed the kit detection level which made it unusable by the Program.

Pesticide analysis in monitoring well samples was fairly consistent with respect to the number of compounds screened for and laboratory reporting limits from 1995 to 2006. During that time period there were a total of 277 detections of 15 different pesticide compounds. The most frequently detected pesticides in order of occurrence were desethyl-atrazine (DEA), atrazine, metolachlor, and prometon. From 2007 to 2011, the list of pesticide compounds screened for doubled in size due to two factors: 1) laboratory equipment and methodology improvements had allowed for evaluation of more compounds and lower reporting limits, and 2) an evaluation of chemical and physical characteristics of pesticide compounds registered for use in Colorado revealed the need to adjust the list so that new compounds were being looked for and negligible compounds were removed. In the last five years of sampling monitoring wells in Weld County, there have been 420 detections of 35 different pesticide compounds. About 58% of total detections are degradation products, indicating that several of the pesticide compounds being used in the area are being degraded through multiple breakdown pathways. Atrazine, metolachlor, and prometon detections accounted for 100% of detections in 1995, 58% of detections from 1996-2006, and only 16% of detections from 2009 to 2011. Currently, the most frequently detected pesticide compounds are the metolachlor degradation products, metolachlor-ESA and metolachlor-OA, with 16.2% and 12.7% of all detections from 2009 to 2011. Only two of more than 900 samples (0.2%) collected in Weld County since 1995 have exceeded an EPA drinking water standard for a pesticide: a domestic well, in 1995, contained 0.9 ppb of lindane, which is greater than the 0.2 ppb standard; and a monitoring well in 2001 contained 5.5 ppb of atrazine, which exceeded its 3.0 ppb standard.

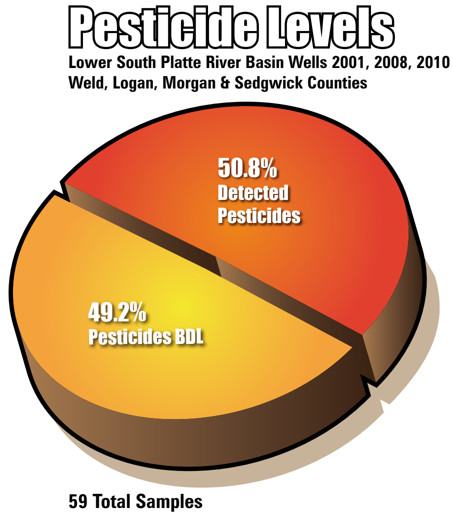
Regional Dedicated Monitoring Lower South Platte—2001, 2008, 2010

Results from the South Platte Basin regional reconnaissance in 1993 showed a median NO_3-N concentration of 9.5 ppm, and 18 of 47 (38%) sampled wells in Morgan and Sedgwick counties showed more than 10.0 ppm. Through cooperation with the USGS and the Lower South Platte Water Conservancy District (LSPWCD),



the Program established a network of 20 monitoring wells that initiates in between Empire and Riverside Reservoirs in far eastern Weld County and terminates in Sedgwick County near the Nebraska state line. This network was intended for long-term monitoring of Colorado's remaining portion of the South Platte alluvial aquifer laying to the east of Greeley and the Weld County sub-regional dedicated monitoring effort discussed earlier. The Program sampled the network for the first time in 2001 and then made plans to sample the network every other year starting in 2008. Samples were analyzed for a full suite of pesticide compounds and nitrate-nitrogen. The laboratory more than doubled the number of pesticide compounds screened for from 47 in 2001 to more than a 100 in 2008 and 2010.

The median NO_3-N concentration in 2001 for the 19 wells sampled was 9.6 ppm with 37% of the wells having NO_3-N above the 10.0 ppm EPA drinking water standard. A maximum of 74 ppm NO_3-N came from a well near Brush that has since been associated with a point source of nitrate contamination. The range of NO_3-N concentrations was 2.2 to 17.7 ppm for the other sampled wells. The median dropped to 5.4 ppm in 2008 and increased back to 8.3 ppm in 2010. In general, about one third of the wells in the network are over the EPA drinking water standard for nitrate, but three wells near or above the standard in 2001,



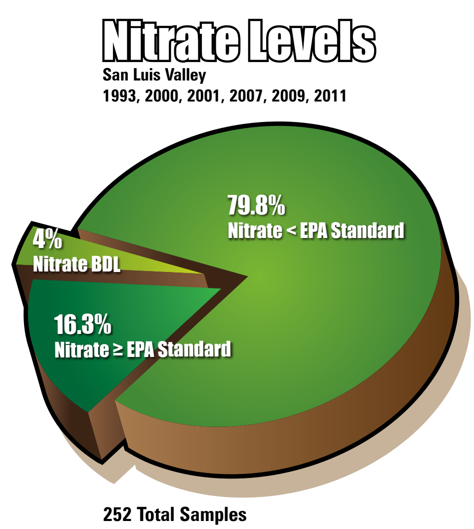
have since decreased to 2.3 ppm or less. The well near Brush contained more than 250 ppm NO_3-N in 2008, prompting the Program to involve CDPHE for investigation into the nitrate's source. A nearby greenhouse operation was suspected of discharging used irrigation water into an unlined pond that was percolating into the alluvial aquifer in the area. Upon request, the Program sampled that well six times from May to November in 2010. The well had an average NO_3-N concentration of 105 ppm over the six events. A Cease and Desist Order was delivered to the greenhouse operation by July of 2011. A check sample was collected from the well in October of 2011, and revealed a NO_3-N concentration of 57.2 ppm.

From 2001 to 2010 there has only been one well with no detectable pesticide compounds. A total of 75 detections have accrued from the three sampling events in the other 18 wells during that time period. Atrazine and DEA have accounted for 13.3% and 18.7% of all detections with the majority of those occurrences coming in 2001. Degradation products accounted for 77% of the total detections in 2010. In particular, metolachlor degradation products have accounted for 38% of total detections, which is similar to findings in Weld County monitoring wells since 2009. The six samples collected in 2010 from the well near Brush, for the purpose of monitoring elevated nitrate concentrations, ended up revealing a plume of atrazine moving through the area at concentrations well above the EPA drinking water standard of 3.0 ppb. A total of 50 detections of 11 different pesticide compounds were discovered in the six samples, but the detections of atrazine at concentrations ranging from 6.2 to 15.4 ppb were the most alarming. The elevated atrazine concentrations were not believed to be associated with the greenhouse discharge. A check sample collected in 2011 showed atrazine concentrations back below one ppb, with the detection of eight different pesticide compounds including a detection of bromacil at 4.3 ppb.

San Luis Valley

Study Area Description

The San Luis Valley (SLV) of south-central Colorado is an intermontane valley bounded by the steep Sangre de Cristo Range to the east and the San Juan Mountains on the west. The two major hydrologic regions in the SLV that could potentially be impacted by agricultural chemical use include the Closed Basin and the Rio Grande River drainage basin. Colorado's portion of the river basin encompasses approximately 7,500 square miles. A 3,200 square mile area of Tertiary/Quaternary basin-fill deposits covering five counties, comprise what is termed the San Luis Valley. The portion of the SLV north of the Rio Grande River is considered the Alamosa Basin or "Closed Basin" because of a topographic divide created by Rio Grande alluvial outwash that causes the Alamosa Ba-



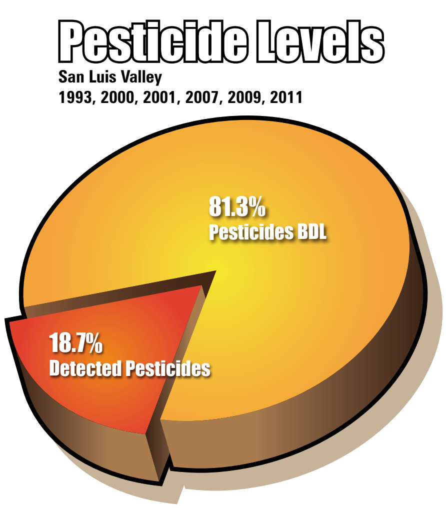
sin to be drained internally, whereas the Rio Grande and its tributaries drain the remainder of the SLV's unconfined basin-fill deposits. The basin also contains a confined aquifer that sits below the clay layers in the upper Alamosa Formation.

The majority of the SLV's economy is based on agriculture. Due to the arid climate and high altitude of the valley (~7,700 feet), the principal irrigated crops are alfalfa, potatoes, barley, wheat, spinach, and lettuce. Pasture on native grasses is the principal dry-land use. SLV farming can be divided into three basic regimes: potato and small grain rotations under center pivot irrigation, vegetable producers who rotate with hay or small grains under center pivot or furrow irrigation, and general livestock in the areas with native meadow hay sustained by a shallow water table. A large portion of the eastern side of the SLV is rangeland or wasteland due to poor soil conditions. A majority of soils in the SLV are coarse-textured and overlay a gravelly substratum. All of these factors, coupled with widespread use of agrichemicals, create a rather significant vulnerability to the SLV's unconfined aquifer quality.

Center pivot irrigation, Rio Grande Basin, San Luis Valley

Regional Reconnaissance—1993

The Program conducted a regional baseline investigation of the quality of unconfined groundwater in 1993. A total of 93 domestic wells were sampled throughout the valley. Samples underwent analysis for nitrate and a suite of 31 pesticide compounds. Nitrate-nitrogen analysis indicated that 13 samples (14%) exceeded the EPA drinking water standard of 10 ppm and 29 samples (31%) contained no detectable nitrate. The median NO_3-N concentration was 3.5 ppm. A detection of lindane at 0.29 ppb was the only pesticide detected in the SLV in 1993, which exceeded the EPA drinking water standard for lindane of 0.20 ppb.



Regional Dedicated Monitoring—1993, 2000, 2007

The USGS sampled a network of 35 monitoring wells installed throughout the SLV in 1993 for the purpose of conducting monitoring efforts for the National Water Quality Assessment (NAWQA) program. The Program was not involved with the initial 1993 sampling, since it had conducted a separate domestic well sampling earlier in the year. However in 2000, the Program worked alongside USGS to conduct the second round sampling of the NAWQA network and utilized the USGS laboratory results in our database. Another sampling of the NAWQA network took place in 2007 in which the Program requested USGS personnel to collect a split sample that could be analyzed at CDA's lab. The groundwater level in the unconfined aquifer declined from 2000 to 2007, which required the re-installation of several monitoring wells to greater depths prior to sampling. Changes in well depth where samples were collected should be taken into account when interpreting results between years. Lab analysis in 2000 tested for a vast array of constituents, since the testing was conducted at the USGS lab; however, the Program's main interests were of the agrichemical constituents, which included nitrate, nitrite, and 47 pesticide compounds. The split samples analyzed at CDA's lab in 2007 underwent analysis for nitrate, while the USGS' lab analyzed the original sample for 81 pesticide compounds.

The median NO_3-N concentration went from 3.0 to 3.9 ppm from 1993 to 2000 in the 33 wells that were sampled in each year. Nitrate above the EPA drinking water standard was discovered in eleven wells (33%) in 1993 and ten wells (30%) in 2000. All wells with this condition were the same in both years except for one well that dropped below the standard. In 2007, the median NO_3-N concentration was 1.23 ppm; however, of the 33 wells sampled, two were new and had not been previously sampled in 1993 or 2000 (both had NO_3-N < 0.2 ppm in 2007); and two other previously sampled wells could not be sampled in 2007 (one had NO_3-N of 24.7 ppm in 2000). It is also important to note that 21 of the 31 wells (68%) sampled in both 2000 and 2007 were re-drilled and installed 14 feet deeper on average into the unconfined aquifer. Of those 21 wells, 14 decreased 0.1 to 28.1 ppm in NO_3-N and seven increased 0.15 to 8.7 ppm from 2000 to 2007. Therefore it is not known whether the lower median in 2007 is due to natural attenuation, improvements in fertilizer use or farm management, and/or changes in well construction.

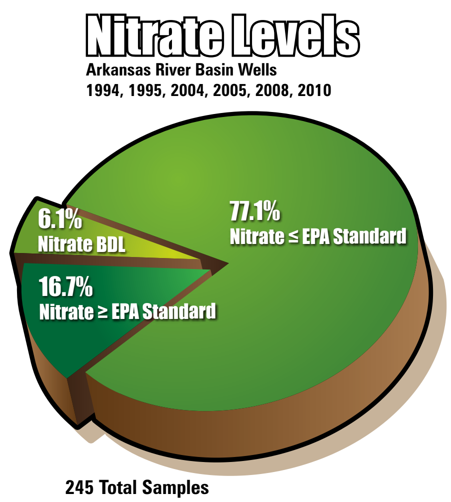
Pesticide analysis in 1993, 2000, and 2007 has mostly resulted in detections of metolachlor and metribuzin, with only 18.2% of 99 total samples resulting in a pesticide detection. In total there have been 12 metolachlor detections and 11 metribuzin detections. No individual well has had a detection of metolachlor or metribuzin in every sampling year, showing the chance of detection is purely random and of very low concentration. Of the 17 instances where metolachlor or metribuzin were detected in a well from 1993 to 2007, only 35% of the time did both pesticides show up in the same well. In 2007, a detection of metalaxyl and another detection of simazine were also found in separate wells.

Regional Dedicated Monitoring—2009, 2011

The Program attempted to acquire access to or install its own collection of monitoring wells in the SLV for the purpose of long-term dedicated monitoring because of the infrequency of the USGS NAWQA program's monitoring schedule for its network. Since 2007, the Program has decided that the SLV requires sampling once every other year. Beginning in 2009, the Program decided to partner with the San Luis Valley Ecosystem Council (SLVEC). Since the summer of 2006, the EPA and SLVEC's Landscape Environmental Assessment Plan—Healthy Inspired Goals for Humans (LEAP-HIGH) project provided free well-water sampling to more than 400 households in the SLV. In 2009, the Program was able to cooperate with SLVEC to gain interest from nearly 100 domestic well owners wanting their wells tested for the presence of agrichemicals in addition to other constituents being measured through LEAP-HIGH's efforts. Upon ensuring the placement of domestic wells into the unconfined aquifer of the SLV within areas of irrigated agriculture, and attaining a distribution of samples as uniform as possible throughout the SLV, a total of 43 domestic wells were sampled in 2009. Samples were collected by Program personnel and shipped to both the Montana Department of Agriculture lab in Bozeman, Montana for analysis of 95 pesticide compounds, and CDA's lab in Denver for analysis of nitrate and two other historically detected pesticide compounds not on Montana's analyte list—metribuzin and lindane. A second sampling of this domestic well network took place in 2011. Key differences were the addition of two new wells and the loss of two wells (keeping the total at 43 sampled wells each year, but 45 different wells between the two sampling events), and analysis for nitrate and 99 pesticide compounds conducted entirely at CDA's lab.

The median NO_3-N concentration for the domestic wells sampled in 2009 and 2011 was 2.0 and 1.6 ppm, respectively. There were a total of nine samples (10.4%) from six different wells that contained NO_3-N above the EPA drinking water standard from 2009 to 2011. Of the 86 total samples, only five (5.8%) were below the nitrate detection limit. There have been 29 of 173 (16.8%) different domestic or monitoring wells sampled since 1993 that have exceeded the EPA drinking water standard. The vast majority of these wells (79.3%) have been discovered in the Closed Basin. All three wells that have accounted for the maximum NO_3-N concentration in the domestic or monitoring well networks in one of the sampling years from 1993 to 2011 have been located in the eastern half of the Closed Basin, eight to eleven miles east of U.S. Highway 285.

A total of 50 pesticide detections were found in 23 of 45 (51%) different domestic wells over two sampling events from 2009 to 2011. The majority of the detections (76%) were discovered in 2009 because of the Montana lab's lower detection limits. While several pesticide compounds were discovered in 2009, the metolachlor degradation products accounted for 63% of all detections, with metolachlor ESA having twice as many detections as metolachlor OA. These two compounds were the only pesticides detected in seven of 43 sampled wells in 2011. Of the 25 wells detecting either of these two compounds in either 2009 or 2011, 44% of them detected both at the same time. Metribuzin, detected historically in all USGS NAWQA sampling years, was not detected in domestic wells sampled in 2009 or 2011. This is at least partly due to the Program's higher detection limit of 0.2 ppb in 2011, compared to the USGS' detection limit of 0.012 ppb. Furthermore, no metribuzin detection has ever been greater than 0.09 ppb.



Arkansas River Basin

Study Area Description

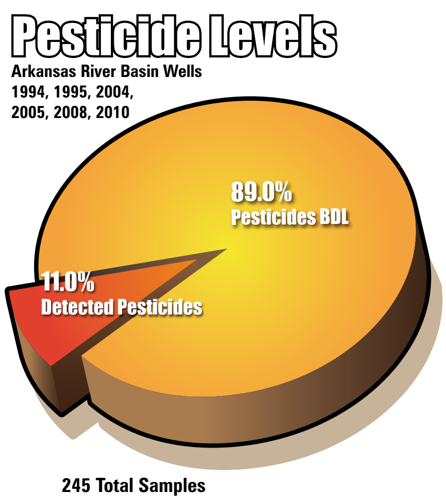
The Arkansas River has its origin high in the Rocky Mountains near Leadville but does not become of particular interest to the Program's monitoring efforts until it exits the mountains west of Pueblo. From Pueblo, the lower Arkansas River alluvium aquifer exhibits more continuity with up to three mile widths as the river flow towards Holly and the Colorado-Kansas state line. Alluvium is not a significant aquifer along many of the Arkansas tributaries, although the Fountain, Big Sandy, and Black Squirrel creeks (all north of the main stem) do have significant alluvial aquifers in direct connection with the Arkansas River alluvium. The valley-fill aquifer is recharged by precipitation, applied irrigation water, and leakage from canals and reservoirs. Land-use in the lower Arkansas River valley is heavily agricultural, with both surface and groundwater being utilized to grow a significant amount of farm crops like alfalfa, corn and sorghum for grain, wheat, and cash crops like onion and cantaloupe. Even though the extent of the alluvium aquifer is not as much as in other basins (i.e., South Platte River), active land-use practices utilizing agrichemicals in both developed areas and agricultural areas, in addition to the aquifer being a significant source of domestic water supply, make the lower Arkansas River Valley an important study area.

Regional Reconnaissance—1994, 1995

The Program collected 139 samples from domestic, stock, and irrigation use wells from Pueblo to the Kansas state line in Prowers County in 1994. Samples were analyzed for nitrate and 30 pesticide compounds at CDA's lab. While several other dissolved solids like chloride, sodium, and sulfate showed median values much higher than is generally preferred for human consumption or irrigation use, the median nitrate concentration was only 4.0 ppm. The maximum concentration was 38.9 ppm, and only 13.6% of all samples exceeded the EPA drinking water standard of 10.0 ppm. Eight wells were below the nitrate detection limit. A detection of 2,4-D was the only pesticide compound found at a quantifiable level.

A follow-up sampling took place in 1995 to determine if the contamination originally detected was representative of groundwater quality at particular sites or just coincidence of timing. A total of 29 samples were collected from wells that either contained nitrate above the EPA standard or were suspected of containing trace amounts of atrazine in 1994. The only sample collection or analysis changes were analyses for only 19 pesticide compounds and a drop in the detection limit for atrazine from 0.5 ppb to 0.1 ppb. Nitrate levels in the re-sampled wells were statistically similar to 1994 with median NO_3-N concentrations of 10.2 and 10.3 ppm in 1994 and 1995, respectively. A total of seven atrazine detections were found, and one well had a detection of 4.2 ppb, which is over the EPA drinking water standard of 3.0 ppb. None of the other 18 pesticide compounds analyzed for in 1995 were found.

Arkansas River Valley as seen from the Fort Lyon Canal

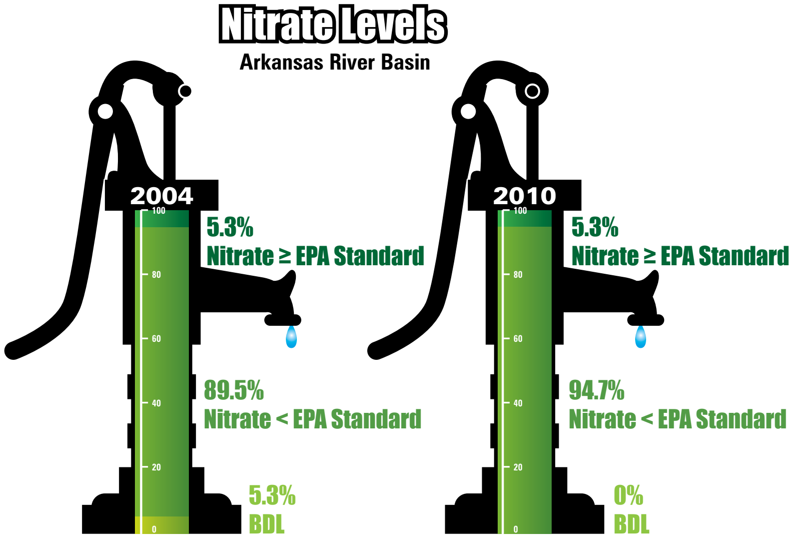


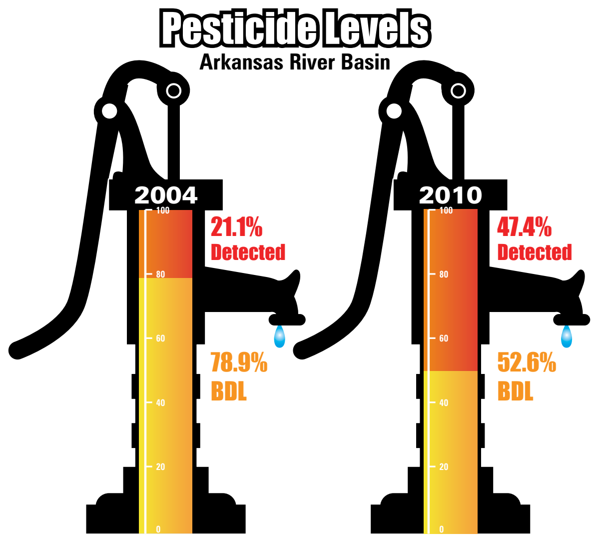
Regional Dedicated Monitoring—2004, 2005, 2008, 2010

The analysis of existing reconnaissance groundwater data, agricultural chemical use data, and aquifer sensitivity and vulnerability models developed by the Program provided a means to prioritize areas for additional monitoring. The Arkansas River alluvial aquifer was lacking in monitoring well coverage and was selected to receive 20 monitoring wells in 2004 installed with funds from an EPA grant. The monitoring wells are located from just east of Pueblo through Otero, Bent, and Prowers counties near the Kansas state line. The criteria for selecting the specific sites of the new monitoring wells were similar to criteria used before: use of agricultural chemicals in significant quantities, depth to groundwater generally less than 50 feet, a representative array of soil types, and a mixture of irrigated and non-irrigated land use. The Program sampled 19 of the 20 wells in 2004 and all the wells in a 2005 follow-up sampling. Sample analysis included nitrate and 47 pesticide compounds in both years. One well was lost due to damage by 2008, so only 19 wells were sampled that year and again in 2010. The number of pesticide compounds screened for increased to 107 in 2008 and 102 in 2010.

The highest median NO_3-N concentration found in the network from 2004 to 2010 was 4.4 ppm. Six of 77 samples (7.7%) were below the nitrate detection limit. About 9% of all samples that measured above the EPA standard for nitrate all came from different wells, which indicates the randomness of high nitrate concentrations in Arkansas River alluvium. Even including the 1995 samples, which were selected as re-samples based on 1994 nitrate measurements being above the EPA standard, the aquifer has only seen 16.7% of 245 samples exceed the EPA standard from 1994 to 2010.

From 2004 to 2010, 19 of 77 (24.7%) total samples have had one or more pesticides detected, but all detections have occurred in just 13 of the 20 wells sampled. A total of 23 detections of 11 different pesticide compounds have been found, with the most detections being of metolachlor-ESA, metolachlor, and desethyl-atrazine. No pesticide detection during the period has exceeded





an EPA drinking water standard. The most pesticides were found in 2010 when 12 total detections were found in nine of nineteen sampled wells.

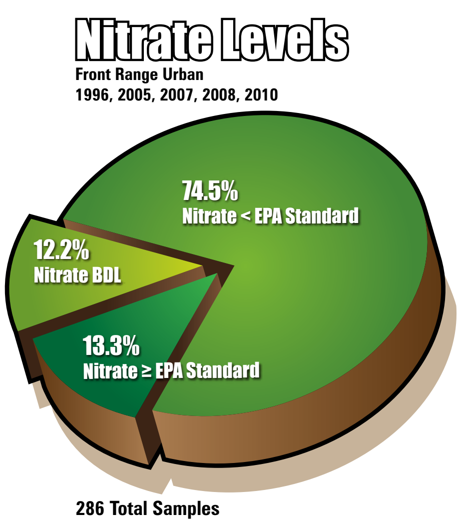
Sub-regional Reconnaissance
El Paso County—2006

El Paso County contains a diversity of landforms ranging from the Palmer Divide and the Black Forest in the north, foothills and Pikes Peak on the west, and grass steppe covering most of the county east of Colorado Springs. This reconnaissance survey included some groundwater samples from the shallow Upper Dawson Formation bedrock aquifer of the Denver Basin, but priority was given to alluvial aquifers along Arkansas River tributary streams. Agriculture in the area mostly consists of irrigated alfalfa hay, some cash crops, a few turf production operations, and grazed rangeland. Urbanization is the other major land use. The expansion of the city's edge, plus an increasing density of sub-divisions evolving in neighboring rural areas, is creating the likelihood of an even more complex array of nitrate and/or pesticide pathways that may affect groundwater quality. The monitoring program sampled 49 wells, a majority of them domestic. Samples were analyzed for nitrate and 47 pesticide compounds.

The laboratory analysis for nitrate concentrations demonstrated that contamination was not a pressing concern in El Paso County. Wells in alluvial aquifers influenced by agricultural activities contained nitrate at higher amounts than other areas in the county. About 86% of the wells contained nitrate but were below the EPA drinking water standard. Six wells (12%) contained no measurable level of nitrate, and only one well exceeded the drinking water standard. No pesticide was discovered at a measurable concentration.

Front Range Urban
Study Area Description

The Front Range Urban (FRU) corridor represents a mostly non-agricultural area that extends from Fort Collins in the north to Pueblo in the south. The majority of sampling efforts have been focused on developed areas that include residential, commercial, and industrial land uses in addition to public landscapes



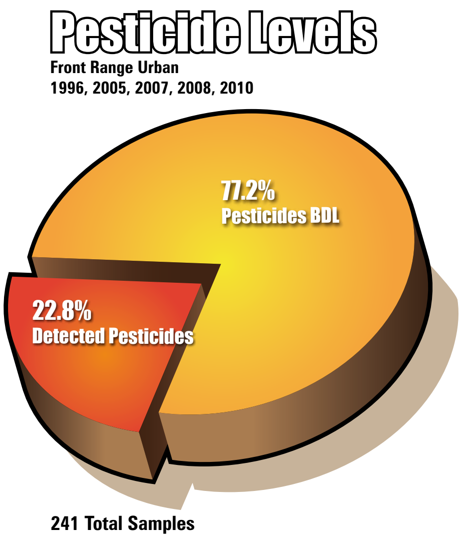
like parks and golf courses. The vast majority of samples in the FRU are collected from alluvial aquifers associated with tributaries, or the main stem, of either the South Platte or Arkansas River. The Program's intent with this study area is to obtain a representative sampling of the major cities along the Front Range in order to understand the urban environment's impact on water quality compared to water quality discovered of irrigated agriculture areas.

Regional Reconnaissance—1996

A sampling of 71 wells in 1996 was the Program's first attempt to study groundwater quality in the urban environment. Most of the wells were privately owned and permitted for domestic use. Because of the difficulties of finding established wells within an urbanized (developed) landscape, many wells were located on the fringe of, or even outside, the urban environment. The distribution of samples provided adequate representation of Fort Collins (FTC), Greeley, parts of Denver-metropolitan (DM), and Boulder County, although many of the Boulder County sites were outside the urban landscape and in more of a rangeland or grazed pasture landscape. Samples were analyzed at CDA's lab for nitrate and 30 pesticide compounds.

The median NO_3-N concentration found in the FRU network in 1996 was 2.6 ppm. About 23% of the sampled wells were below the detection limit with two-thirds of those coming from Boulder County. Seven

The Front Range's population density creates special monitoring challenges.



wells (9.9%) were above the EPA drinking water standard. Of the 71 samples, nine were from monitoring wells predominantly installed in cities within Weld County that lay more in a mixed agricultural-urban setting. The results from these nine wells show a median NO_3-N concentration closer to ten ppm with five wells exceeding the EPA standard. If these results are not included with the other 62 sampled wells, the FRU network shows a median NO_3-N concentration of only 2.3 ppm.

There were a total of 45 detections of four different pesticides—atrazine, prometon, DEA, and bromacil. One or more of these pesticides were found in 25 of the 71 sampled wells. The most frequently detected pesticide was prometon with 24 detections. Of the nine monitoring wells sampled, six contained 14 pesticide detections. The 30 wells sampled in Boulder County only had four wells with detections. No detections exceeded any established EPA drinking water standards.

Regional Dedicated Monitoring—2005, 2007, 2008, 2010

The Program initiated efforts to establish a long-term monitoring well network within cities along the Front Range corridor in 2005. Study area coverage and sample distribution were improved in 2007 and 2008. DM and Greeley were the only FRU cities reasonably represented by the 40 monitoring well samples collected in 2005. Poor sample distribution and clustering left room for improvement. Of the 45 samples collected in 2007, 38 were in the DM area and were well dispersed across DM except for lack of representation in the most northern and northwestern portions. The Program attempted to acquire access to or install new monitoring wells in Boulder, Colorado Springs (CS), FTC, Loveland, and Pueblo in order to expand coverage in 2008. Due to time and budget restraints, or due to the inability to work out agreements with city officials or well owners, the Program was not able to achieve good sample coverage in every city. Samples were collected from 67 wells in 2008 and 63 wells in 2010 with good coverage in DM, FTC, CS, and Greeley. Samples from every year were analyzed for nitrate and pesticides but the number of pesticide compounds varied from 47 in 2005 to more than 100 in subsequent years.

From 2005 to 2010, a total of 216 samples were collected from 104 different monitoring wells. The median NO_3-N concentration of all samples is 4.0 ppm. This median value is higher than what was discovered during reconnaissance sampling in 1996 (2.6 ppm); however, the large number of domestic well samples from non-urban areas of Boulder County that year, and the exclusive usage of monitoring wells from 2005 to 2010 (monitoring wells are usually installed at shallower depths than domestic wells), is likely the reason. About 21% of all wells and 15% of all samples from 2005 to 2010 contained NO_3-N concentrations above the EPA drinking water standard. There were 14 wells (13%) that tested below the detection limit one or more times from 2005 to 2010. CS (22 total samples) had a median NO_3-N concentration of 8.2 ppm and 32% of its samples above the EPA drinking water standard—both values were the highest among cities sampled. DM has had 147 samples collected from 70 different wells, but only 12% of the samples have exceeded the EPA drinking water standard. Meanwhile, Greeley has had 14 samples collected from four wells and has never had a NO_3-N concentration above the EPA standard.

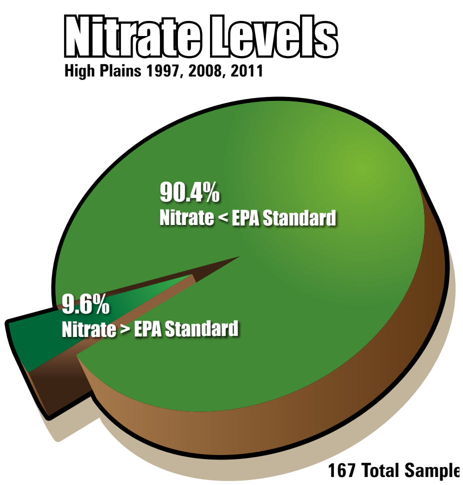
Only three wells (7.5%) detected a pesticide in 2005, and all three detections were of the herbicide MCPP in northeastern DM. Due to complications at CDA's lab, no pesticide results were available for samples collected in 2007. Only samples collected from monitoring wells in DM were found to have pesticide detections in 2008. Four wells (5.9% of all wells) had detections with two being of bromacil, and one each of dichlorvos and prometon. Several new pesticide compounds were added to the screening list between 2008 and 2010, which partly explains why there were 31 detections of 11 different pesticides in 23 of 63 wells (37%) in 2010. Imazapyr was the most frequently detected with nine detections. DM had pesticide analysis ran on 109 samples from 70 different wells from 2005 to 2010. Of those samples, 18% accrued 25 detections of 12 different pesticide compounds, which accounts for 66% of the total pesticide detections in the FRU during that time period. No pesticide detections from 2005 to 2010 were above any established EPA drinking water standards.

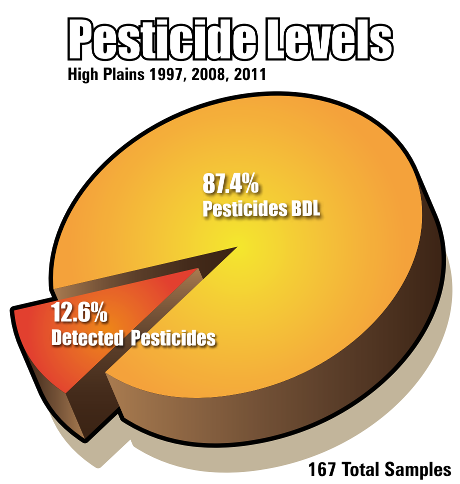
High Plains

Study Area Description

The High Plains aquifer (HP) is an extensive regional aquifer that underlies approximately 174,000 square miles of the Great Plains states (South Dakota, Wyoming, Nebraska, Colorado, Kansas, Oklahoma, New Mexico, and Texas). It is composed principally of the unconsolidated to semi-consolidated sands, gravels, clays, and silts of the Miocene-aged Ogallala Formation. Quaternary age alluvial, valley-fill, dune sand, and loess deposits are also considered a part of the HP where they are hydraulically connected to the underlying Ogallala Formation. In Colorado, the HP is present beneath all or parts of 13 counties in the eastern third of the state which is referred to regionally as the High Plains. This regional area includes most of the state east of the Rocky Mountain foothills, but excludes the valleys of the South Platte and Arkansas Rivers. Water from the HP is the primary source of domestic and irrigation water for residents in the region. Agriculture is the basis for the economy in much of the HP, and irrigation is necessary in most years for certain crops, and in some years for all crops. Use of groundwater for irrigation plays a major role in the agricultural economy of the HP, with the total number of irrigated acres exceeding 600,000, or approximately 17% of all irrigated cropland in Colorado. While coarse-textured soils, the presence of extensive irrigated agriculture, and the use of agrichemicals does suggest a risk to groundwater quality, the depth to groundwater in the aquifer makes the overall risk lower than the risk determined for alluvial aquifers like that of the South Platte River. The depth to groundwater in the HP ranges from 50 feet on the western edge to more than 150 feet along the eastern boundary of Colorado.

Wheat harvest on the High Plains





Regional Reconnaissance—1997

The Program began its investigation of HP water quality in 1997 with the collection of 129 samples mostly from domestic wells, but also some irrigation and municipal wells. The majority of the wells were located in the portion of the HP laying between the South Platte and Arkansas rivers, and about 15 wells were located south of the Arkansas River. Samples were well distributed within the HP study area with the exception of a cluster of nine public supply wells (PSW) sampled for the town of Springfield. All samples were analyzed for nitrate and 47 pesticide compounds at CDA's lab.

The median NO_3-N concentration was 2.6 ppm and every well contained a detectable quantity of nitrate. Approximately 6% of the wells exceeded the EPA drinking water standard, and the maximum concentration was 32.8 ppm. The wells exceeding the EPA standard were mostly located in the general vicinities of Wray, Burlington, and Springfield. A total of 21 detections of four different pesticide compounds were discovered in 14 wells (10.8%). Atrazine and its degradation product DEA accounted for 76% of all detections. One PSW sampled in Springfield contained 3.9 ppb of atrazine, which is above its drinking water standard of 3.0 ppb, and two additional PSWs (all within a quarter mile of each other) were close to exceeding the standard with atrazine concentrations of 2.4 and 2.8 ppb. In total, five of the nine Springfield PSW's contained nearly half of the total pesticide detections discovered in the HP in 1997. So while this clustering of samples was not good for sample distribution over a regional area, it was important in the discovery of nitrate and atrazine contaminated drinking water in a public supply system. Fortunately, the well exceeding the atrazine standard was not being used for public supply.

Regional Dedicated Monitoring—2008, 2011

In the summer of 2008, the Program contracted the services and expertise of the USGS to assist in the establishment of a monitoring well network in the HP. The criteria used for determining suitable areas for monitoring wells included: location within the Ogallala Formation, a saturated thickness of 50 feet or more, a maximum depth to groundwater of 180 feet (budget limitation), and location within an area of irrigated agriculture. USGS provided the Program with 30 potential monitoring well sites through randomized distribution of points within equal area polygons of land meeting the above criteria. Due to budget constraints, the Program could only install 20 monitoring wells from near Holyoke to south of Burlington. Although all 20 wells could not be sampled in 2008 or 2011, between both sampling events, all 20 wells were sampled at least once. The Program's laboratory analyzed samples for nitrate and more than 100 pesticide compounds in both years. The types of pesticide compounds analyzed for differed between years.

Nitrate-nitrogen results for 2008 and 2011 showed a median concentration of 5.8 and 4.9 for each year, respectively. The maximum concentration discovered in 2008 was 32.9 ppm from a well east of Holyoke. Unfortunately, the well was damaged and unable to be sampled in 2011, so the maximum NO_3-N concentration of 18 ppm in 2011 was from a different well but was still in the northern half of the network. Approximately 21% of the 38 monitoring well samples collected from 2008 to 2011 contained nitrate above the EPA standard, and all wells had detectable concentrations of nitrate. There were only two detections of the herbicide dicamba, in 2008, at concentrations far below the EPA drinking water standard of 200 ppb. By 2011, the pesticide analysis screen had incorporated several pesticide degradation products, so the number of detections went up significantly. Five wells (26%) accrued a total of 13 detections of five different pesticide compounds (DEA, simazine, alachlor ESA, metolachlor ESA, and metolachlor OA). About 92% of those detections were of degradation products.

West Slope (Western Colorado)

Study Area Description

The West Slope in Colorado is considered to be all land west of the Continental Divide. There are over 38,000 square miles and elevations ranging from 7,000 to more than 14,000 feet above sea level. The mountains are composed of mixed geomorphology. The majority of the area's precipitation (up to 40 inches per year) occurs as winter snow pack which, during spring melt, recharges alluvial aquifers bound to the major stream valleys. Most of the Program's groundwater sampling efforts occur in these alluvial deposits but have also included some non-alluvial aquifers associated with larger mesas. The dominant land cover in this region is forest and rangeland. Alfalfa hay and grass hay in pasture areas are the major crops, but some areas of the larger river valleys (Grand and Uncompahgre Valley) have provided opportunity to produce irrigated wheat, corn, and beans, as wells as fruit orchards and vineyards. Groundwater has not been extensively developed in the majority of the area since most incorporated municipalities rely on surface water. However, most rural residents depend on groundwater for their domestic wells. While various alluvial, sedimentary, and igneous aquifers exist throughout the area, the majority of domestic use is derived from the more economical, higher producing, and shallower alluvial deposits which consist of mixed boulders, gravel, sand, and silt with thickness ranging from 20 to more than 100 feet.

Regional Reconnaissance

West Slope—1998, 2000

The first sampling effort was conducted in 1998 using 81 domestic wells from across the West Slope region. This baseline sampling event included most of the alluvial aquifers adjacent to the region's major rivers, but coverage was not uniformly distributed within or between aquifers. In 2000, the Program was able to collect samples from ten monitoring wells in the area from Clifton to Grand Junction in the Grand Valley, which is mostly Colorado River alluvium. The Grand Valley is about 40 miles long, stretching from Palisade to west of Mack, and is one of the largest valley-fill alluvium deposits on the West Slope. The ten sampled wells were located within an eight mile area between Clifton and Grand Junction. Three of the monitoring wells were in Gunnison River alluvium upstream of the confluence. Samples from both years were analyzed at CDA's lab for nitrate and 45 different pesticide compounds.

The median NO_3-N concentration for the West Slope in 1998 was 1.4 ppm with only five wells (6%) greater than or equal to five ppm. The maximum from one well north of Craig was 32 ppm, exceeding the EPA drinking water standard. A confirmation sample from that well in 1999 showed it had dropped to 14.8 ppm. About 36% of the wells sampled were below the nitrate detection limit. The median for the ten monitoring wells sampled in the Grand Valley was 6.8 ppm with six of the wells below the detection limit. Only one well was over the EPA standard at 16 ppm. Of 91 samples collected from 1998 to 2000 only a single detection of the insecticide malathion was discovered. The well with this detection was also resampled in 2000 and resulted in no detectable pesticide compounds.

Sub-Regional Reconnaissance

Tri-Rivers Area—2009

Reevaluation of the expansive West Slope led the Program to split it into three more manageable sub-regions in 2009: Northwest, Tri-River, and Southwest. Each area has different characteristics with respect to water consumption and land use/land cover, and varying levels of vulnerability to contamination from agrichemicals. By surveying these smaller areas, effort can be applied to getting sample density in areas of irrigated agriculture and/or areas of intense oil and gas productivity. The Program decided groundwater in the Tri-River area was the most vulnerable and had the highest potential for contamination due primarily to the large amount and variety of irrigated agriculture in the different valleys, but also due to the high density of oil and gas activity and its associated herbicide use within areas of shallow groundwater.

The Tri-River area includes alluvial aquifers associated with the Colorado River, North Fork Gunnison River, Uncompahgre River, and Plateau Creek which lie within Garfield, Mesa, Montrose, and Delta Counties. Only four wells from the 1998 reconnaissance sampling were able to be included for the Tri-Rivers sub-regional sampling due to missing contact information. None of the ten monitoring wells sampled in 2000 was available and/or suitable for the Program's use. In total, 63 domestic well samples were collected, but two of the wells, which did not have pumps installed, were sampled using monitoring well sampling methodology. All samples were analyzed for nitrate at CDA's lab and for 90 different pesticides at Montana Department of Agriculture's lab in Bozeman, Montana.

Only two samples (3%) contained NO_3-N concentration above the EPA drinking water standard of 10.0 ppm, but both of these wells contained more than 100 ppm NO_3-N as well as excessively high levels of other dissolved salts like sulfate, calcium, and sodium. The median NO_3-N concentration was only 0.6 ppm and only three wells (4.7%) contained more than five ppm. A total of 35 detections of 11 different pesticide compounds were discovered in 19 wells (30%). Over half of the total detections were degradation products of the herbicides acetochlor, alachlor, atrazine, and metolachlor. About three quarters of the detections were in wells sampled in the North Fork Gunnison and Uncompahgre Valleys. Only one pesticide detection was discovered from nine samples collected in Plateau Creek Valley. The most frequently detected pesticide compound was alachlor ESA with nine detections. No established EPA drinking water standards for pesticides were exceeded.

North Park

North Park Basin

Study Area Description

The North Park Basin (NPB) lies entirely within Jackson County and is bounded by the Park Range to the west, the Medicine Bow Mountains and Never Summer Range to the east, Rabbit Ears Range to the south, and Independence Mountain and the Wyoming border to the north. This intermontane valley encompasses an area of 1,190 square miles with elevations ranging between 8,000 and 9,000 feet. The principal bedrock aquifers in the NPB consist of Tertiary sedimentary rocks with the poorly to moderately consolidated conglomerate, sandstone, siltstone, and shale configuration of the Coalmont Formation being the main hydrologic unit. Groundwater in the upper part of the Coalmont Formation is generally unconfined with depth to water ranging from one to 298 feet. NPB is drained by the North Platte River and its major tributaries—Michigan, Canadian, and Illinois rivers. About 93% of the established wells in NPB are designated for domestic or livestock use, but they only account for about 9% of the total annual groundwater withdrawals. Coal mining in Jackson County accounts for the majority of groundwater withdrawals, but overall, groundwater withdrawals account for less than 0.5% of the total water used annually in the county. Cropland accounts for only 10% of the land use in Jackson County with 51% of that being irrigated hay production.

Regional Reconnaissance—2000

A total of 21 domestic wells were sampled in the North Park Basin in 2000. Samples were analyzed for nitrate and 45 pesticide compounds at CDA's lab. According to laboratory results, no significant nitrate impact exists in Jackson County. The median NO_3-N concentration was 0.7 ppm. Nearly half of the wells were below the detection limit, and only one well was greater than five ppm. No wells exceeded the EPA drinking water standard. Pesticide analysis did not reveal any measurable concentrations.

Wet Mountain Valley

Study Area Description

The Quaternary alluvium and Tertiary valley-fill deposits of the Wet Mountain Valley (WMV) are located almost exclusively in Custer County with only the most northern portion reaching into Fremont County. This intermontane basin located between the Sangre de Cristo and Wet mountains covers approximately 230 square miles. Oak, Texas, and Grape creeks—Arkansas River tributaries—drain the basin. The area is primarily agricultural with most cultivated land (lying mostly in hay) making up the more water-abundant west side and rangeland lying mostly on the east side. Depth to water has been reported to be from a few feet to more than 300 feet below land surface. Similar to the North Park Basin described earlier, groundwater withdrawal represents a small percentage of Custer County's total water use. Surface water provides the predominant water supply for the area. Groundwater withdrawals are primarily used for irrigation, public water supply, domestic use, and livestock watering.

Regional Reconnaissance—2002

In 2002, a regional groundwater quality study was conducted in the portion of the WMV

Wet Mountain Valley

in Custer County. The 57-well network assembled for this project was a joint effort with the USGS Pueblo sub-district and Custer County. While USGS utilized the wells in a water supply study for Custer County, coverage was not uniformly distributed, but all geographic and hydrogeologic areas in WM were represented. Efforts were concentrated in areas representative of recent development. Samples were analyzed for nitrate and 36 pesticide compounds at CDA's lab.

The median NO_3-N concentration was less than one ppm, and only one well exceeded the EPA drinking water standard with a concentration of 11.6 ppm. About 17% of the wells were below the detection limit and 40 wells (70%) contained less than 2.5 ppm. A single detection of the herbicide picloram was the only pesticide discovered.

Mountainous Region

Study Area Description

Colorado's Precambrian crystalline and Tertiary igneous rocks represent a unique and expansive aquifer system. The terrain surrounding these aquifers includes high peaks, great relief, rugged terrain, steep slopes, and shallow soils. Major land cover is exposed bedrock, forests, and mineral resources with the primary industries being logging, mining, and tourism. The Precambrian crystalline rocks occupy about 12% of Colorado's surface area and are concentrated mostly in the central part of the state from the Wyoming border to the New Mexico border. Composition of the Precambrian age formations are igneous and metamorphic rocks; largely granites, gneisses, and schists. The younger Tertiary age igneous rocks generally lie west of and between the outcrops of Precambrian rocks. They are characteristic of areas where widespread volcanic activity resulted in a high variable collection of tuffs, breccias, and surface flows. The water storage capability of these bedrock aquifers is highly variable and generally low compared to alluvial and sedimentary aquifers because of the discontinuity and a lack of primary porosity.

Sub-Regional Reconnaissance

Gilpin County—2005

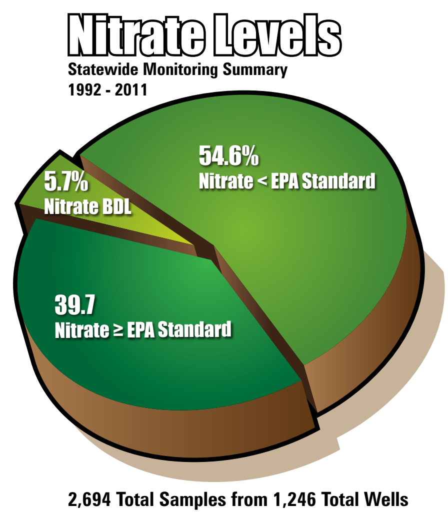
Gilpin County is located in the Rocky Mountains' Front Range. Besides Black Hawk and Central City, mountain subdivisions make up all development. A Gilpin County CSU Extension agent contacted the Program in 2004 to inquire about the Program sampling for pesticides in the county. More than two dozen residents were concerned about weed spraying and development's effect on water quality. The Program was able to accommodate sampling for 27 well owners. Samples were analyzed for nitrate and 47 pesticide compounds at CDA's lab.

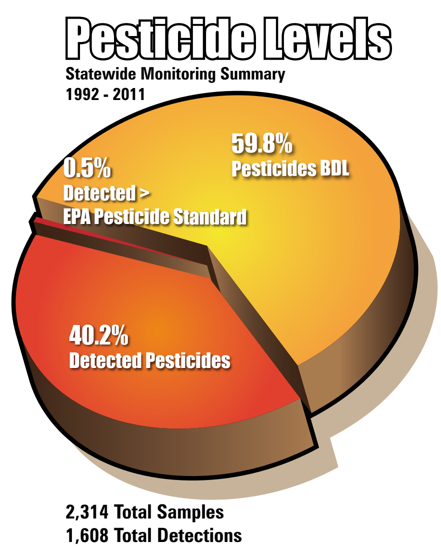
It was discovered that the majority of the area had very minor levels of nitrate contamination. One-third of the wells sampled were below the detection limit. The other two-thirds of the samples contained nitrate below the EPA standard with fifteen containing less than 5 ppm NO_3-N. No pesticide compounds were detected at measurable concentrations.

Statewide Monitoring Summary

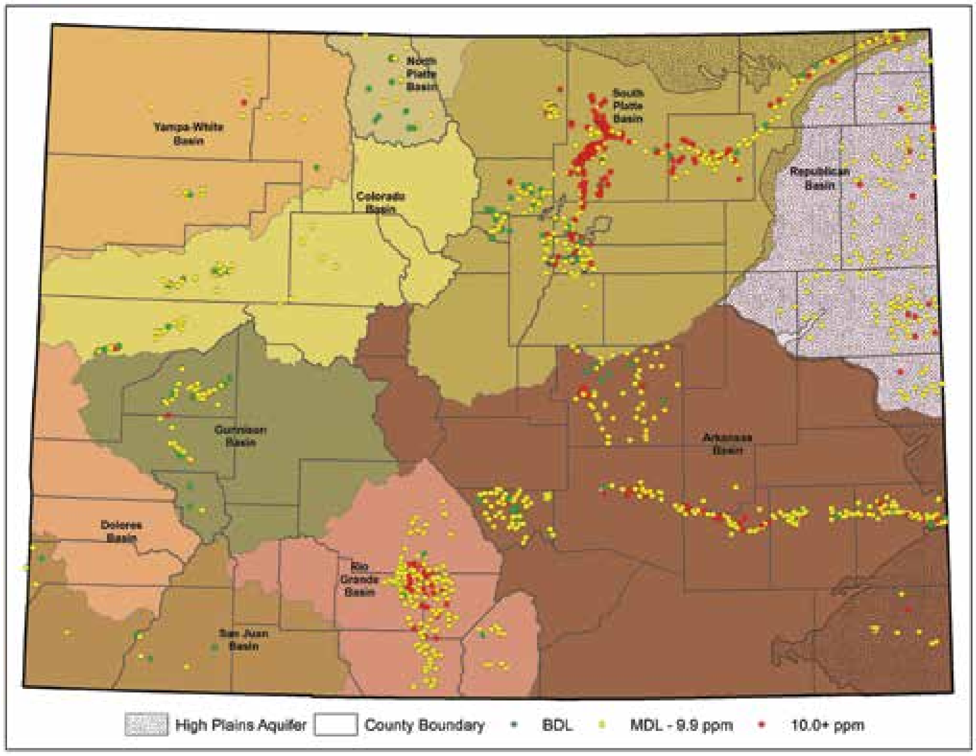
Through collection of nearly 2,700 samples from 1,246 wells, the Groundwater Protection Program has learned much about Colorado's groundwater quality during 20 years of monitoring. In fact, this is the largest data set of Colorado groundwater quality information with respect to nitrate and pesticides that exists today. In addition, water quality data on many inorganic constituents has been collected for many locations. While not reported in this publication, it can be found on the Program's online database that was launched in 2007 to provide the general public and government entities access to Colorado groundwater quality information. The Web address for the database is http://www.colorado.gov/ag/db.

Several areas of the state have been identified as having significant nitrate contamination at levels that exceed the EPA drinking





Statewide Summary, Nitrate-Nitrogen, 1992-2011



water standard. Included are portions of the South Platte alluvial aquifer, the San Luis Valley unconfined aquifer, and smaller sections along the Arkansas River. Because of the findings, the Program will focus attention on more intensive monitoring and educational efforts to prevent additional contamination and improve nitrogen management.

Statewide monitoring data shows that 39.7% of all samples were equal to or greater than the EPA NO_3-N drinking water standard of 10.0 ppm; however, only 272 wells (21.8%) contributed samples toward that end. Approximately 46% of all samples collected by the Program have come from the 138 wells (domestic, irrigation, and monitoring) in the Weld County dedicated monitoring network. Samples collected from 1995 to 2011 in the Weld County network have accounted for nearly 80% of all samples with a NO_3-N concentration above the EPA drinking water standard. Statewide, about 55% of samples and 68% of wells have contained measurable NO_3-N, but are below the EPA standard. Almost 6% of samples and 10% of wells have been below the nitrate detection limit statewide.

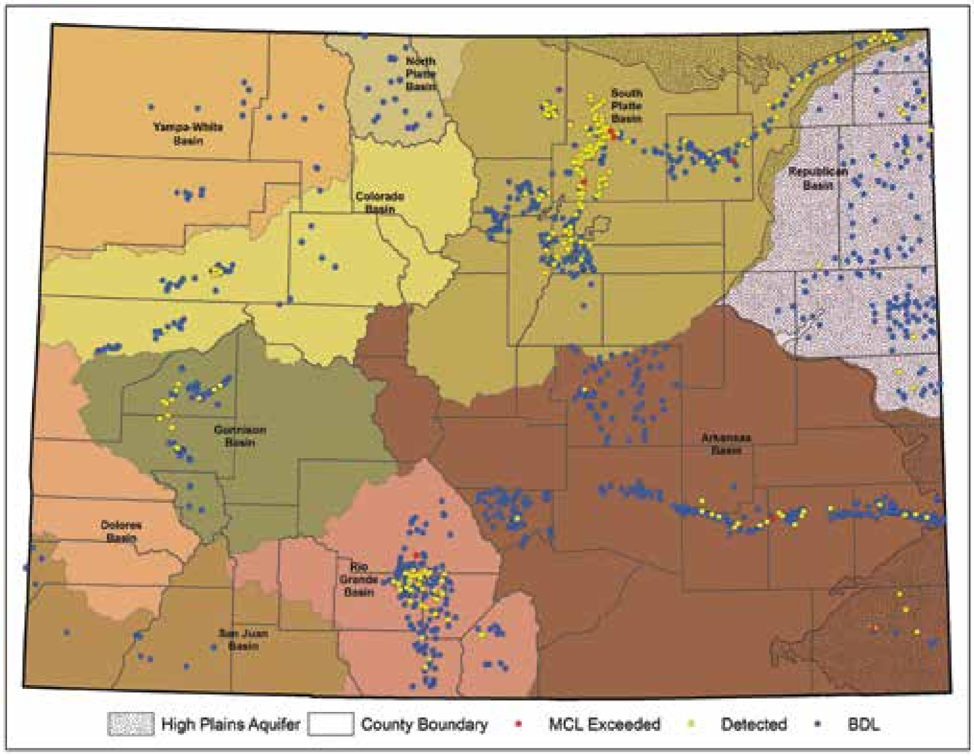
In comparison to nitrate detections, pesticide detections are relatively rare and generally occur at very low concentrations. As a reminder, not every sample collected by the Program was analyzed for pesticides. The total number of samples analyzed for pesticides was 2,314—380 fewer than was analyzed for nitrate. While the sample numbers were quite different, there was less variation in the number of wells sampled with only 32 of 1246 sampled wells (2.5%) never having undergone any pesticide analysis. Statewide, there have been an accumulation of 1,608 pesticide detections in 930 samples (40.2%) from 304 different wells (25.0%). A total of 54 different pesticide compounds have been detected. Weld County dedicated monitoring networks have accounted for approximately 78% of total detections although this is at least partly due to the higher sampling frequency for the network (40% of samples collected statewide and analyzed for pesticides). About 31% of the Weld County detections were of triazines, which were discovered through the use of an immunoassay screen on domestic and irrigation wells from 1996 to 2004. Since 2007, when the Program increased its pesticide screen to more than 100 compounds and achieved lower detection limits with advances in instruments and methodologies, there have been 638 detections, which means nearly 40% of total detections have been discovered since this comprehensive report was first published in 2007.

More than 96% of statewide pesticide detections have been of herbicides and their degradation products. Historically, atrazine, metolachlor, and prometon have been the three most frequently detected pesticides. Statewide there have been 901 detections (56% of total detections) of these three or their degradation products (desethyl-atrazine, desisopropyl-atrazine, hydroxy-atrazine, metolachlor-ESA, and metolachlor-OA). However, metolachlor and its degradation products have alone accrued 202 detections, which are 12.6% of all detections and roughly one-third of 604 total detections since 2009. At least three-quarters of all pesticide detections have had a concentration less than half a part-per-billion. Only seven samples (0.3%) from seven different wells (0.58%) have contained a pesticide at a concentration exceeding an established EPA drinking water standard, which indicates the rarity of finding a pesticide above an established standard. Four of these were violations of the drinking water standard for atrazine.

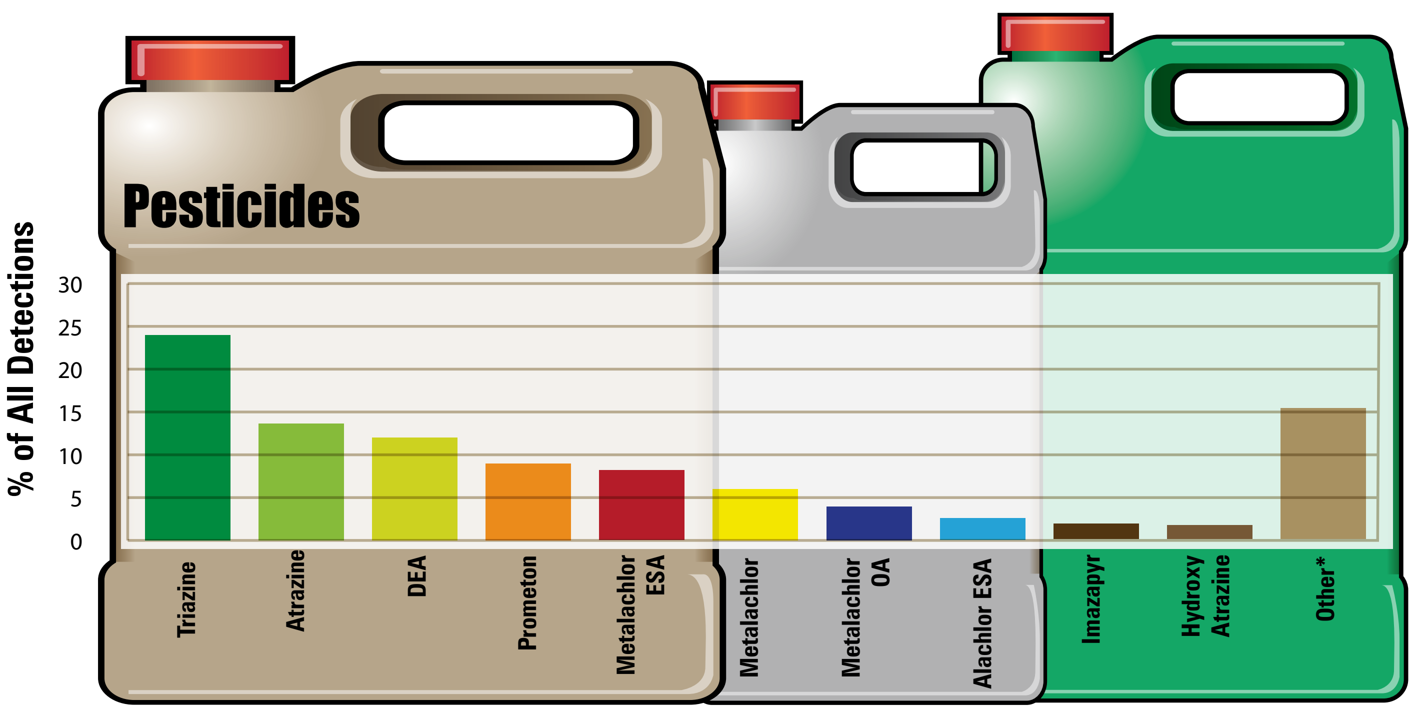
References

US Environmental Protection Agency, 2009. Groundwater & Drinking Water. http://water.epa.gov/drink/contaminants/index.cfm

Statewide Summary, Pesticides, 1992-2011



Summary of Statewide Pesticide Detections



From 1992-2011, researchers detected one or more pesticides in 304 of 1214 (25.04%) wells sampled for pesticide analysis. The most commonly detected compounds, as seen above, are Atrazine, Triazines (which includes Atrazine), DEA (Atrazine breakdown product), Prometon, Metolachlor and its breakdown products (Metolachlor ESA and Metolachlor OA), Alachlor ESA (Alachlor breakdown product), Imazapyr, and Hydoxy atrazine (Atrazine breakdown product).

**Other constitutes 251 detections of 44 different pesticide types that have accrued over the time period. No one pesticide accounted for more than 1.9% of 1608 total detections.*

Education and Training

Development of Best Management Practice Publications

The legislation creating the Agricultural Chemicals and Groundwater Protection Program specifies that the Commissioner of Agriculture is authorized to enter into an agreement with Colorado State University Extension to provide education and training on how to reduce groundwater contamination from agricultural chemicals [C.R.S. 25-8-205.5(3)(f)]. CSUE works with the Colorado Department of Agriculture to develop best management practices for Colorado farmers, landowners, and commercial agricultural chemical applicators. The Colorado Water Quality Control Act defines BMPs in this context as "any voluntary activity, procedure, or practice…to prevent or remedy the introduction of agricultural chemicals into groundwater to the extent technically and economically practical" (Colorado Revised Statutes, 1990).

Numerous BMP guides assist Colorado growers, chemical applicators, landowners, and homeowners in better protecting Colorado's groundwater resources.

Because of the site-specific nature of groundwater protection, chemical users must ultimately select the BMPs appropriate for their situations. The local perspective is necessary to evaluate the practices' feasibility and economic impact. For these reasons, the Groundwater Protection Program Advisory Committee recommends a significant level of local input be solicited before the BMPs are accepted. The Advisory Committee and a technical review team's input and review are also important components in this process.

Early in the program's history, CDA and CSUE jointly published factsheets that provided generalized BMPs for water quality and agricultural chemical use, storage, and handling. Then in 1995, CSUE published Best Management Practices for Colorado Agriculture, which included broad BMPs addressing nutrient, pest, and water management. This publication, created in notebook form, included chapters about:

- Nitrogen fertilization
- Phosphorus fertilization
- Manure utilization
- Irrigation management
- Crop pests
- Agricultural pesticide use
- Pesticide storage and handling
- Private well protection

These documents provide templates for local BMP development committees and other entities developing recommendations. Information is updated as technology improvements and continued research adjusts recommendations. For example, the chapters on manure, pesticide, phosphorus, and nitrogen management were revised in 1999, 2010, 2011, and 2012, respectively. Private well protection has been revised and reprinted in 2005 and 2009.

CSUE also piloted a local BMP development process in the Front Range area of the South Platte Basin, San Luis Valley, Lower Gunnison Basin, and the lower South Platte Basin. Beginning in 1993 in the Front Range/South Platte Basin and San Luis Valley, local working committees—consisting of small groups of producers, consultants, and chemical applicators—began work on BMP development. Localized BMPs for the Front Range/South Platte Basin were published in *Best Management Practices for Irrigated Agriculture.*

In 1995, the Shavano Conservation District began working with local CSU extension agents and producers to develop *Best Management Practices for the Lower Gunnison Basin* appropriate for the West Slope. During 1996, the Lower South Platte Basin local BMP work group was initiated and their findings were published in *Best Management Practices for the Lower South Platte River Basin.* Although most of these

From the beginning of the Groundwater Protection Program, the producers' cost to implement BMPs has been a legitimate concern. Therefore, an economic analysis was performed to determine the cost of implementing BMPs that required purchasing a service or product to adopt the practice.

work groups have been inactive since finishing their local publications, the guides are still distributed at the local and state levels.

Building on these efforts, the first crop-specific BMP publication, *Barley Practices for Colorado—A Guide for Irrigated Production,* was published in 1997 with cooperation and funding from Coors Brewing Company. In 2003, *Best Management Practices for Colorado Corn* was published with support from the Colorado Corn Growers and through a grant from the EPA Nonpoint Source Pollution Program. Individual chapters of this guide have been revised in the online version to reflect changes in corn production technology since first published. More than 4,000 copies reached corn producers through distribution to Colorado Corn Growers' members, county extension offices, the NRCS, and the Groundwater Protection Program. The greenhouse industry was specifically addressed in *Pollution Prevention in Colorado Greenhouses* in 1998. These crop and industry directed BMPs allow for more specific practices to be communicated and enhances ownership of the practices by the targeted group.

From the beginning of the Groundwater Protection Program, the producers' cost to implement BMPs has been an important concern. In 1996, an economic analysis was performed to determine the cost of implementing BMPs that required purchasing a service or product to adopt the practice. This information was condensed into two fact sheets:

- *Economic Considerations of Nutrient Management BMPs, revised in 2011*
- *Economic Considerations of Pest Management BMPs*

With cooperation from the Colorado Environmental and Pesticide Education Program, CSUE developed and published the pocket-sized *Pesticide Record Book for Private Applicators* for growers to record restricted use pesticide (RUP) applications according to federal law. The booklet also contains water quality and pesticide safety BMPs, sprayer calibration guidelines, and numerous equations and conversions to help private applicators correctly apply pesticides. The record book is typically revised and reprinted at least every two years. CSUE has distributed approximately 1,500 booklets each year since 1997. In 2011, information and tables for recording Worker Protection Safety information was added. Additionally, an *Excel* spreadsheet based recordkeeping system was developed to aid users in keeping electronic pesticide application records. This program is provided to potential users online.

CSUE also developed the pocket-sized *Irrigated Field Record Book* to help growers improve irrigation water management. Records of water application timing and amount are essential to good crop management. Along with record keeping tables and guidance, the booklet contains equations for determining flow, application depth, soil moisture tables, and crop water use information. CSUE cooperated with the NRCS in 2004 and 2007 to print and distribute more than 5,000 copies.

Increasing development in previously rural areas created a new water quality audience—the rural small acreage landowner. While not major users of agricultural chem-

Pocket-sized record books help producers track restricted pesticide use and irrigation management.

Homeowner's Guides were developed to encourage pesticide and fertilizer BMPs in urban settings.

icals in terms of total product used, new rural residents have the potential to affect water quality. They rely on groundwater for their primary drinking water source and utilize septic systems for wastewater treatment. Thus, education is needed to explain how to prevent drinking water supply contamination. In response, *Best Management Practices for Private Well Protection* was revised in 2005 and 2009 to a more comprehensive publication, *Protecting Your Private Well.* This publication has been enhanced with additional resources including well and septic system recordkeeping folders, an online water quality interpretation tool, Well Educated factsheets, and an educational DVD developed in cooperation with Montana State University through a USDA/NIFA regional water protection program.

Urban use of pesticides and commercial fertilizers can also have an impact on groundwater resources. In 1996, BMP fact sheets on urban pesticide and fertilizer use were developed and distributed in cooperation with the City of Colorado Springs. Four BMP fact sheets were originally developed as part of a response to the detection of the insecticide diazinon in Colorado Springs storm water:

- *Homeowner's Guide to Protecting Water Quality and the Environment*
- *Homeowner's Guide to Pesticide Use Around the Home and Garden*
- *Homeowner's Guide to Alternative Pest Management for the Lawn and Garden*
- *Homeowner's Guide to Fertilizing Your Lawn and Garden*

The series was revised and reprinted in 2002 and 2012 when the fact sheet, *Homeowner's Guide to Household Water Conservation,* was added to the series. These documents have been widely distributed throughout the urban Front Range.

Other Educational Efforts

CSUE also uses other avenues to provide information to affected individuals and organizations, as well as the general public. A display booth is used at conferences and trade shows to provide local groundwater quality monitoring results, publications, and regulatory information. Throughout the state, extension agents present information on radio shows, in mass media, through news releases, and at meetings.

For example, local agents and the Colorado Water Well Contractors Association collaborated to host numerous educational meetings around the state for real estate agents and small rural acreage landowners. CSUE also offers technical assistance to water conservancy districts, groundwater management districts, and other local entities interested in helping rural residents.

The initiation of the National Certified Crop Advisor (CCA) program in Colorado in 1995 provided another mechanism for training and education. More than 345 individuals in Colorado have passed the national and state exams and gained sufficient experience to become Certified Crop Advisors in Colorado. More than 160 are currently active registered advisors. They must obtain continuing education credits to maintain their certification. Continuing education affords an ideal opportunity to provide information on chemical use and groundwater protection to advisors and consultants who make recommendations to farmers.

Increased use of online information by all segments of society, including farmers, provides new ways to reach audiences. Beginning in 1998, a Groundwater Protection Program Web site, http://www.colorado.gov/ag/gw opened. It offers many program publications and links to other reliable sources. Publications are also available online at CSUE websites:

- www.ext.colostate.edu
- www.csuwater.info
- www.region8water.colostate.edu

Demonstration Sites and Field Days

Field demonstrations are an integral part of illustrating BMPs' effectiveness and practicality. When feasible, the cooperating producer conducts much of the fieldwork and demonstration setup, which increases the BMP's creditability with farmers and their neighbors. Field demonstrations have been conducted with cooperation from organizations such as the Colorado Corn Growers Association, water and natural resource conservancy districts, the NRCS, and agricultural businesses. Specific demonstrated include:

- Nitrogen credits in irrigation water and manure
- Nutrient management planning
- Limited irrigation
- Conservation tillage in irrigated systems
- Irrigation scheduling using soil moisture monitoring and evapotranspiration
- Irrigation system adjustments
- Surge irrigation
- Water measurement
- Soil testing laboratory comparisons
- Polyacrylamide (PAM) use
- Pest scouting
- Pre-sidedress soil nitrate testing (PSNT)
- Alternative herbicides

Newsletters, news releases, brochures, field days, websites, and other methods are used to communicate the results of field demonstration projects. The economic value of adopting a BMP is always highlighted.

Applied Research

Applied research is problem-driven and seeks to develop a product or process that solves the problem. The Groundwater Protection Program has conducted or sponsored applied research intended to develop, test, or verify BMP effectiveness and practicality. The work is completed with internal resources as well as external grants. Most were conducted with the collaboration of CSU faculty, USDA/ARS researchers, and others. Noteworthy field research projects include:

- Reducing nitrate leaching through in-season nitrate and leaf chlorophyll testing
- Refining nitrogen credit recommendations for irrigation water nitrate
- Effectiveness of linear polyacrylamide to prevent sediment and nutrient loss
- BMP development for corn production
- Evaluation of atmometers to predict reference evaporation
- Volatilization of ammonia from sprinkler-applied swine effluent
- Evaluation of runoff water quality from mountain hay meadows
- Validation of alternative manure management systems for confined feeding operations
- Evaluation of the phosphorus index for predicting phosphorus runoff from irrigated crop fields
- Impact of surface water quality from high altitude golf courses
- Reduced tillage impacts on water quality under surface irrigation
- Limited irrigation cropping systems

CSU Extension integrates applied research with demonstration sites and educational field days. The intent is to interest

Demonstration sites help to show the effectiveness and practicality of BMPs in actual field settings.

producers in techniques or management practices that protect water quality while maintaining or improving profitability.

Assessing BMP Adoption

An atmometer estimates crop water use to help better schedule irrigation.

Significant resources have been used to develop, encourage, and extend BMPs to producers for irrigated crop production. At the Groundwater Protection Program's inception in 1990, little quantified information existed about the number of Colorado producers using BMPs and their locations. Work began in 1996 to obtain quantifiable information about specific BMPs in use and producers who maintained productivity while protecting the environment. The information is necessary to conduct relevant education programs, research, and training in the areas and topics most needed. The data also help to document the producers' progress in protecting water quality and to identify where more effort is needed.

Surveys were mailed in February 1997, December 2001, and February 2011 to obtain information on BMP adoption. The 1997 and 2001 surveys included questions on nutrient, pest, pesticide, and irrigation management, whereas the 2011 survey was focused on nutrient management and the costs growers are incurring to implement nutrient BMPs. This latest survey also included a section on precision agriculture.

For all three surveys, the USDA National Agricultural Statistics Service (NASS) determined representative samples of all irrigators in the state from their crop production database. A total of 3,281, 3,240, and 2,000 surveys were mailed in 1997, 2001, and 2011, respectively. Usable response rates were 42, 39, and 37 percent for years in the same order.

The results were grouped into six geographic regions: South Platte, Eastern Plains, Arkansas Valley, San Luis Valley, Mountains, and Western Slope. Survey authors defined the regions based on known differences in water sources and cropping opportunities.

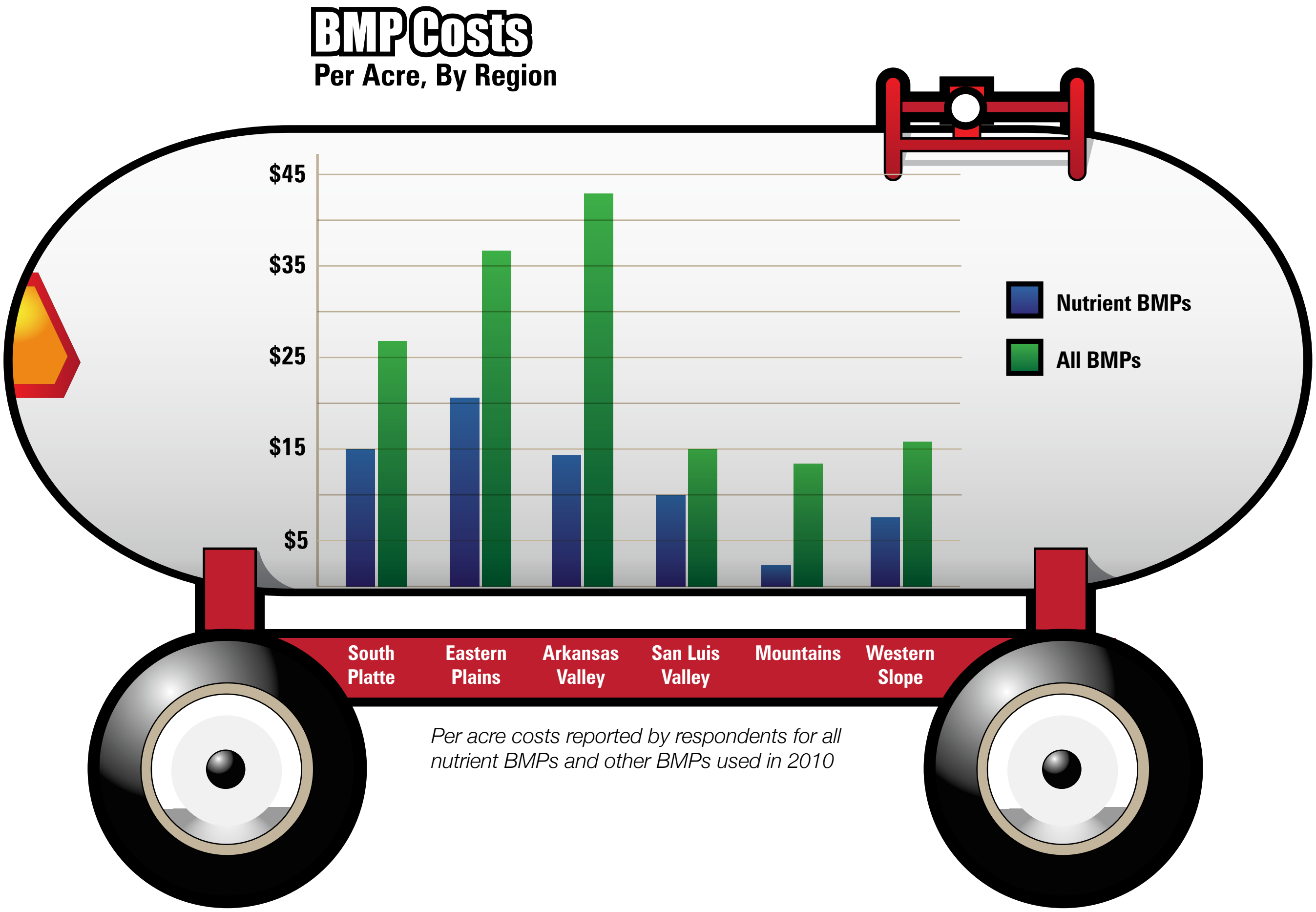
A full description of the 1997 survey methodology and results is published in *Irrigation Management in Colorado: Survey Data and Findings* (Frasier and others, 1999). The 2001 survey methodology and results are published in *Survey of Irrigation, Nutrient, and Pesticide Management in Colorado* (Bauder and Waskom, 2005). A full report on the 2011 survey results is not published at the time of this printing, but survey methodology and most nutrient results are available in *Colorado Nutrient Management Practices 1997-2011: Costs and Technological Advances* (Keske, C. M.H., and others, 2011).

Nutrient Management BMP Adoption

Overall, the results from these surveys show Colorado farmers use key fertilizer and nutrient management BMPs at a reasonable level for their situations. Statewide, more than half the respondents selected soil test analysis as the most common practice. Slightly less than half, though, said they keep written fertility records. As one would expect with Colorado's diverse agriculture, strong regional differences exist among BMP adoption rates that reflect cropping diversity, fertilization practices, and respondent characteristics.

For example, plant tissue analysis was more commonly reported in areas such as the San Luis Valley where fertigation, or injecting chemicals through an irrigation system, is most prevalent. On the Eastern Plains, producers said they relied on paid crop consultants for nutrient management guidance, and were more likely to soil test across a high percentage of their acreage.

The 2011 survey queried producers about the costs incurred with BMPs they might have used during the previous growing season. These costs can include laboratory costs, labor, materials, and consulting fees, for example. As expected, the areas of the state with higher levels of BMP adoption tend to spend more on these practices. Average reported per acre expenditures for the 2010 cropping season for all nutrient BMPs ranged from a low of $2.20 in the Mountains to slightly more than $20 per acre in the Eastern Plains. It is important to point out that many of these



Per acre costs reported by respondents for all nutrient BMPs and other BMPs used in 2010

costs also have benefits, such as improved yield or reduced fertilizer expenses, but others do not have net return for the producer. In many cases, cost-sharing programs from the USDA Natural Resources Conservation Service (NRCS) and other programs can help producers with these expenses and improve adoption.

Adoption of selected nutrient management BMP's from 2011 survey							
	Region						
	S. Platte	E. Plains	Ark. Valley	San Luis Valley	Mtns.	W. Slope	Colorado
Nutrient BMP	% Respondents Reporting Use						
Soil Test Analysis	76	87	45	54	23	47	59
% Acreage Sampled*	60	80	41	69	20	45	56
Take Plant Samples	12	23	6	22	4	5	12
EstablishYield Goals	41	52	33	33	16	17	32
Keep Written Records	52	68	35	53	29	32	46
Paid Crop Consultant	59	45	29	30	20	31	40
None Selected**	12	6	25	30	47	38	25
*Acres sampled in last three years **No BMPs listed on questionnaire reported							

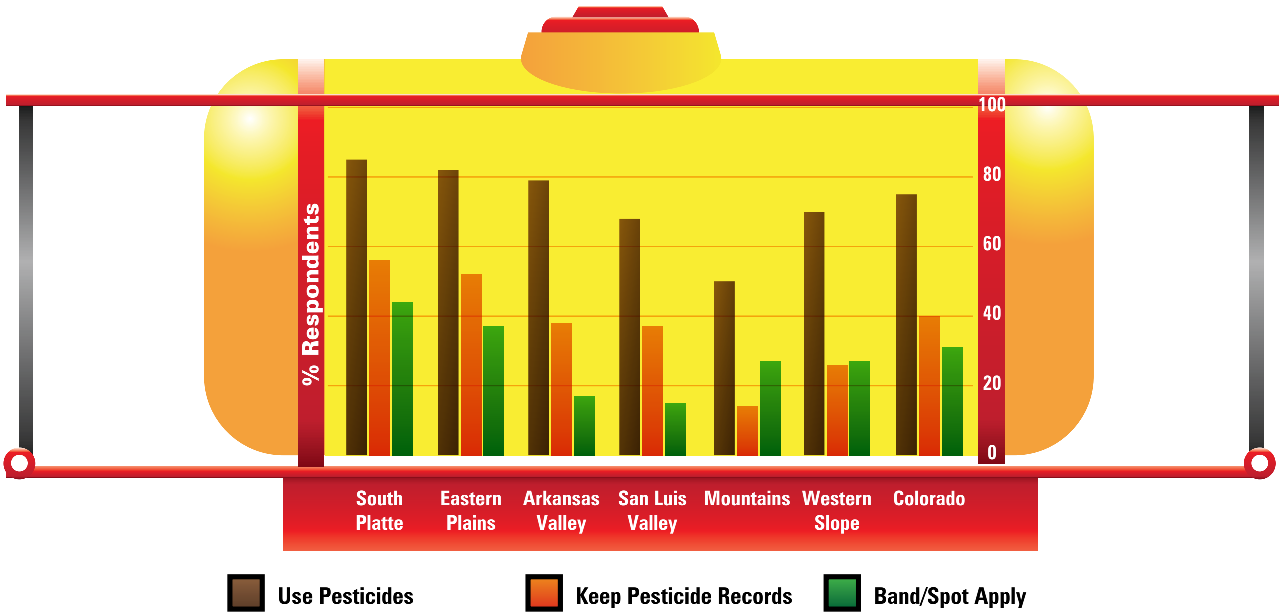
Pest Management BMP Adoption

Controlling crop pests—such as weeds, insects, and diseases—represents a significant percentage of crop costs. Pesticides, including herbicides, fungicides, and insecticides, are frequently used for pest control. However, a wide variety of other practices can be employed, some in combination with pesticides, to manage pests. Many of these practices are included in the concept of Integrated Pest Management (IPM) that is widely promoted over an approach that relies solely on chemicals.

Field scouting, or the practice of monitoring crops for pest populations, was reported in use by more than 50% of the respondents statewide and by more than 75% in some areas. In many places, crop consultants perform the field scouting and provide pest control advice to growers. Ensuring the advice is agronomically and environmentally sound is a focus of the Groundwater Protection Program through program educational efforts and training Certified Crop Advisors.

Record keeping is another IPM practice

Adoption of Selected Pesticide BMPs



Selected pesticide BMPs reported by survey respondents. Results are an average of the 1997 and 2001 surveys.

Adoption of pesticide management BMPs averaged across 1997 and 2001 surveys							
	Region						
	S. Platte	E. Plains	Ark. Valley	San Luis Valley	Mtns.	W. Slope	Colorado
Pesticide BMP	% Respondents Reporting Use						
Field Scouting	70	78	64	62	28	46	58
Use Crop Consultants	39	58	27	40	7	13	30
Economic Thresholds	48	59	47	37	7	20	37
Resistant Varieties	37	46	49	29	9	29	33
Crop Rotation	64	68	76	60	5	39	56
Biological Controls	8	13	8	7	6	14	11
Pest Forecasting	14	19	11	20	0	6	12

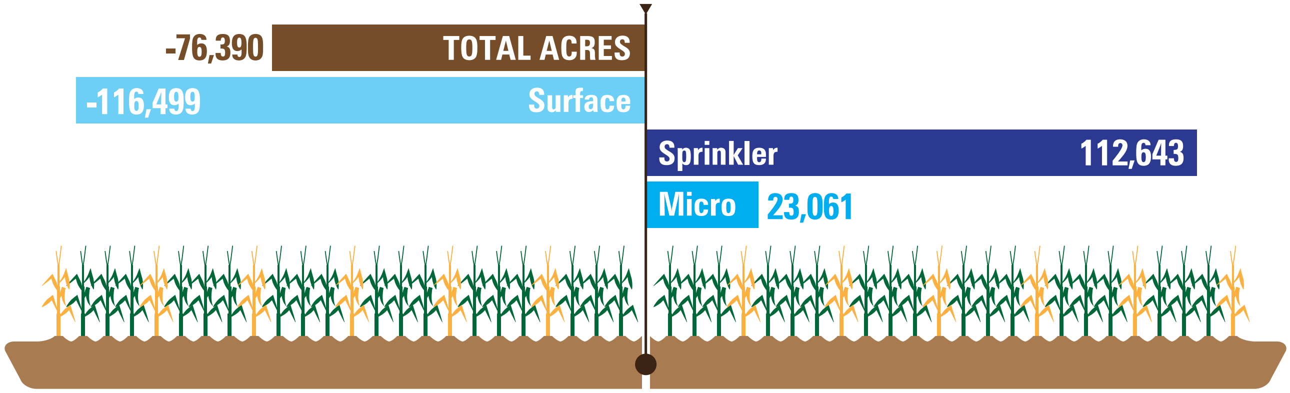
and recommended BMP that helps growers track outbreaks, reduce pesticide resistance by rotating chemical families, prevent crop damage from carry-over, and reduce liability from misapplied pesticides. Pesticide record keeping is also required by law for restricted use pesticides. However, only 40% of pesticide users statewide reported keeping these records. As previously described, the pocket-sized *Pesticide Record Book for Private Applicators* and an Excel spreadsheet were developed to help growers improve their record keeping in Colorado.

Irrigation Management BMP Adoption

Irrigation BMPs include both structural and management improvements. Structural improvements generally include upgrades to existing irrigation systems or changes to a different system. Many are intended to increase the irrigation uniformity and/or efficiency of a particular system. These improvements generally decrease the amount of runoff or leaching that occurs during an irrigation event and the potential for off-field chemical movement as well. Frequently, installation costs for structural improvements are cost-shared with the NRCS. One significant change that has occurred is the conversion of surface to sprinkler and drip irrigation systems. While total irrigated acreage in Colorado decreased by approximately 76,000 acres, sprinkler and drip irrigated acres increased by nearly 136,000 acres from 1998 to 2008 according to the USDA National Agricultural Statistics Service (NASS). These converted systems conserve water at a field scale and reduce the potential for water quality impacts. They also offer producers more flexibility with applying chemicals during irrigation and reduce labor requirements.

Two key irrigation BMPs are determining

Change in Irrigation System Acres



Change in acreage by irrigation system from 1998 to 2008 as reported by USDA/NASS

when to water and how much to water at each irrigation to help prevent under and overwatering. The percentage of growers reporting the use of irrigation management BMPs is generally lower than structural BMPs, suggesting this area requires more attention. While careful use of nutrient or pesticide inputs usually offers a cost savings to producers, the same is not always true for water. This dilemma was reflected in the methods respondents reported using to determine when to water. More precise scheduling methods, such as monitoring soil moisture and evapotranspiration (ET), had lower use than less precise scheduling methods like crop appearance and the producer's experience in our survey and according to USDA NASS (2008). Significant outreach and education have been put toward improving the adoption of these practices, especially since the drought of 2002.

Irrigation management BMPs can have more physical and policy barriers than nutrient or pesticide BMPs. Lack of control over when and how water is delivered can significantly affect irrigation scheduling. This is reflected by groundwater users, who have more control over their water supply than surface water users, reporting higher use of more precise irrigation timing methods, such as soil moisture and ET, or crop water demand.

Irrigation scheduling methods reported by respondents in 2001-2002 survey and the 2008 irrigation census by NASS.* Percentages do not sum to 100% because respondents selected more than one method.

Methods Used to Schedule Irrigation	Respondent's Water Source			
	All Surface Water	All Ground Water	Mixed Water	2008 NASS
	% Using Method			
Experience	48	43	60	NA
Crop Appearance	37	30	51	75
Ditch Schedule	28	2	33	28
Calendar/fixed	22	9	19	26
Crop Consultant	1	30	10	10
Soil Moisture Methods	8	42	18	41
ET methods	2	9	12	7
Other	23	28	12	20

*National Agricultural Statistics Service data includes all irrigators

Overall BMP Adoption

For almost every BMP category, the region, farm size and income level, cropping system, irrigation water source, and other factors influence the choices producers make. BMP adoption rates are typically higher among growers who use commercial fertilizers and pesticides, which indicates a key audience is being reached. Implementation of more specialized BMPs, such as biological controls, pest forecasting, and nutrient crediting is lower. This may indicate a greater level of knowledge required to use some BMPs, and a limited applicability to many cropping systems.

Overall, the two surveys suggest producers accept many of the irrigation, pesticide, and nutrient management BMPs

Center pivot irrigation

that help protect water quality and farm profitability. Adoption of nutrient and pesticide management BMPs is generally higher than irrigation management BMPs. Irrigation system improvements, or structural BMPs, are common in most regions. But adoption of irrigation management BMPs used to determine when and how much to water is not as common.

Practices that have an obvious economic benefit, such as soil sampling and pest scouting, seem to be used more often than those where the economic return is less obvious. For example, record keeping for pest, nutrient, and irrigation water is not widely practiced, as growers likely do not believe they will benefit from the time invested. However, there were considerable differences in adoption rates between region, crop mix, water source, and irrigation system. Water source, either groundwater or surface water, appeared to have the largest impact on irrigation management.

Conclusion

Colorado growers have come a long way towards adopting many effective BMPs, but may never achieve full adoption of all defined BMPs. However, full adoption may not be required or necessary to meet water quality goals in many situations. Additionally, new technologies, farming methods, crops, and other circumstances continue to redefine BMPs and the ease with which they can be adopted. The recent advances in precision agriculture and sub-surface drip irrigation illustrate how technology pushes and enables BMP adoption. All sectors of the agricultural community must continue working to improve and implement the practices that protect Colorado's water resources. The Groundwater Protection Program's educational program will be a key to helping the agricultural community meet this challenge.

References

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USDA NASS - Farm and Ranch Irrigation Survey. 2008. Volume 3. Special Studies. Part 1. AC-07-SS-1.

USDA NASS - Farm and Ranch Irrigation Survey. 1998. Volume 3. Special Studies. Part 1AC-97-SP1.

Monitoring Well Installation Procedures

Well Installation and Sampling

A hollow-stem continuous flight auger (HSA) drill rig is the Program's preferred method for drilling monitoring wells. Other methods exist and may be used in the future by the Program if necessary, but as of now, only HSA has been used. Drilling with HSA churns up cuttings which are logged at five foot intervals or whenever a change in lithology is detected. An 18 to 24 inch length core sample is taken with a hammer-driven split-spoon sampler at each five foot interval from the surface to the water table. All this information is documented in a field logbook and is used to create a lithologic log and provide necessary information for required well permits. Typical data gathered for each drilled well may include:

- Lithologic description and remarks
- Soil type, color, moisture, and consistency
- Borehole depth and diameter
- Penetration resistance (blow counts for hammer-driven split-spoon sampler)
- Estimate of groundwater depth
- Perched water zones
- Date drilled
- Method of sample collection and ID number
- Project identification and location
- Well identification and completion/ construction data
- Names of both the geological professional and the licensed drilling company

In compliance with Rule 6.3 of the Water Well Construction Rules (2 CCR 402-2), the Program files a *Notice of Intent* (Form GWS-51) to the Colorado Division of Water Resources (DWR) at least three days (but not more than 90 days) prior to any monitoring well drilling and construction. In the event a constructed well will be of temporary use (less than one year), then pursuant to Rule 5.2.31, the Program will submit a *Well Construction Report* (Form GWS-31) which references the appropriate Notice of Intent within 60 days of construction and then within a year, will submit a *Well Abandonment Report* (Form GWS-9) indicating the temporary well has been properly abandoned and sealed. In most cases the Program intends to monitor long-term, and therefore must submit a *Monitoring and Observation Well Permit Application* (Form GWS-46), along with any necessary supplemental material, within one year of drilling and construction of the monitoring well. Upon completion of the permitting process, a permanent well permit is issued by DWR. Any time a permitted well becomes damaged, goes dry, or a request is made by the landowner for the well to be removed, the Program submits Form GWS-9 upon properly abandoning and sealing the well.

Drilling a monitoring well (above) and the completed well (below).

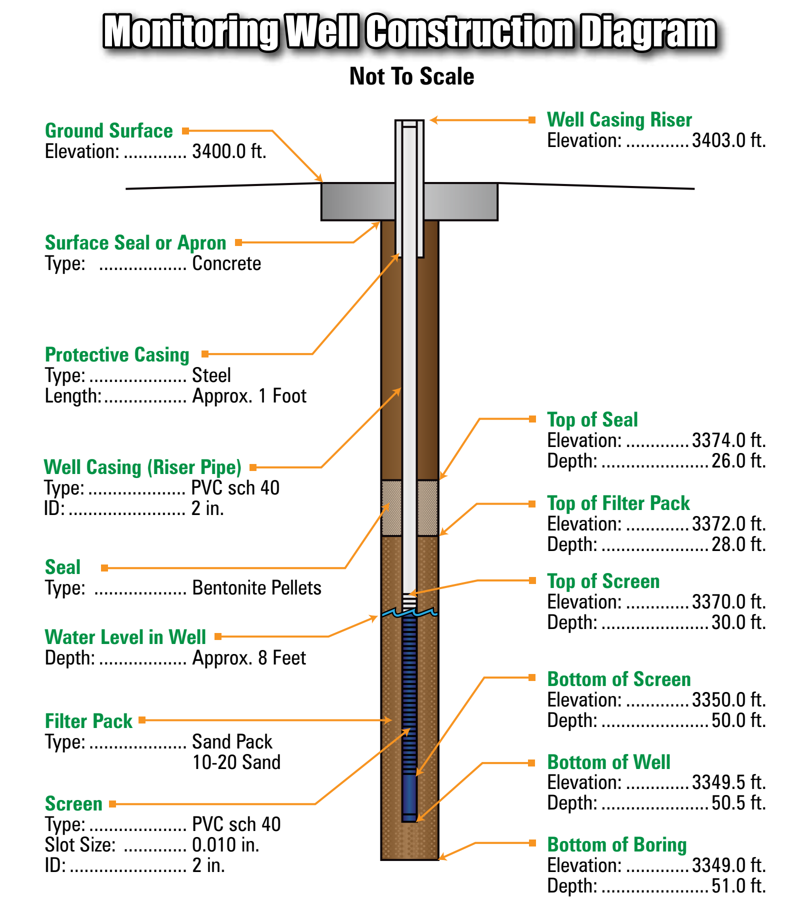
Well casings were constructed of two inch schedule 40 ASTM-approved polyvinylchloride (PVC) pipe. Pipe sections were flush threaded to prevent the introduction of contaminants such as glue or solvents into the well. All installed well casings and screens were cleaned prior to emplacement to ensure all oils, greases, and waxes had been removed. After each monitoring well installation, all down-hole drilling equipment was decontaminated with steam cleaning, Liquinox, and water rinse.

Well Construction and Completion

Well construction materials can vary depending on the type of aquifer being drilled (some geologic material may be more accommodating than others) and the monitoring intentions for the area. The Program, for the most part, installs single-casing, single-screen monitoring wells, which are designed to provide a discreet sampling of a single portion of the aquifer being studied. Occasionally, more than one well may be installed at the same location (well cluster) at increasing depth in the aquifer to monitor for quality differences in thicker aquifers. Well casing diameters for monitoring well installations typically range from two to six inches and mostly depend on the access need for monitoring equipment to be used. The diameter of the borehole must be at least two inches greater than the casing diameter to be used in order to provide a minimum two inch annular space between the borehole wall and the casing. Nearly all wells installed by the Program are drilled with a 4¼-inch diameter hollow-stem auger, which serves as a temporary casing to hold back collapsible material (commonplace for many alluvial aquifers) while well construction material is installed through the auger's axis. The majority of wells used by the Program are constructed of two-inch diameter SCH-40 PVC solid casing with the screened portion being two inch diameter 10 Slot (0.010 inch) SCH-40 PVC. The top of the screened portion is strategically installed at or just below the top of the water table for single well scenarios, and at varying depths beneath the top of the water table for well cluster scenarios. The length of the screened portion is dependent on the yield of an aquifer formation and/or how discreet of a location in the aquifer is desired to be sampled. Typical screen lengths are ten feet.

The two-inch annular space mentioned above is critical in the proper functioning of a well when filled with an appropriate filter pack. The filter pack is cleaned silica sand with an effective size that is dependent on the slot size of the screened casing and also the diameter of the formation material where the screen is to be placed. Most of the Program's wells use a 10-20 silica sand (effective size is 0.04-0.05 inch) that does not allow the filter pack to come through the slotted screen, but yet does not discourage natural flow from the aquifer formation into the well void. The filter pack is installed from the bottom of the borehole to two feet above the top of the screened casing. Any annular space that is produced as the result of the installation of well casing in a borehole provides a potential channel for vertical movement of water and contaminants, unless the annular space is properly sealed. An annular seal of bentonite pellets (or bentonite slurry) is placed from the top of the filter pack to about two feet below the land surface. The last two feet of annular space is filled with a surface seal mixture of quick-setting concrete and granular bentonite. Then, either a solid, steel stick-up protective casing or the flange of a flush-mount protective casing (both should be lockable for security) is installed around the well casing, into and secured by the surface seal material. On the land surface an appropriately sized concrete apron is formed around the protective casing as the final piece of well construction. All diameters, construction material types and/or volumes, and placement depths must be documented in Form GWS-31, which is submitted to the DWR.

CDA - Ag. Chems & GW Protection Program	**Well Number: MW-01**
DATE DRILLED: 03/04/2004 — Location Coordinates	**PROJECT:** Ark River MW Network
INSPECTED BY:	
COMMENTS: Site Details	**JOB NO:**
	INSTALLED BY: Drilling Company



DATE COMPLETED: 3/4/04
CASING (RISER) ID: .... 2 IN.
SCREEN LENGTH .... 20.0 FT.
SCREEN SLOT SIZE: .... 0.010 IN.

ALL ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL

Well Development

Following monitoring well construction, natural hydraulic conductivity of the formation must be restored through the use of a surge and purge technique. Development of a well removes all foreign sediment and ensures turbidity-free groundwater samples. Development is normally completed two weeks after completion of drilling. All well development equipment is decontaminated with Liquinox prior to use and rinsed twice—first with tap water, then with a final deionized water rinse. The development process is mechanical with the use of a surge block (circular, rubber disc) attached to a rod that is plunged up and down in the screened portion of the well. This plunging action forces water inward and outward through the filter pack. Then an appropriate pump is used to pump the water from the well. This process is repeated until the pumped water contains little or no suspended sediment.

References

Nielsen, David M. and Ronald Schalla. 2006. "Design and Installation of Ground-Water Monitoring Wells." Pp. 639-805 in *Practical Handbook of Environmental Site Characterization and Ground-Water Monitoring, 2nd Ed.*, edited by David M. Nielsen. Boca Raton, FL: CRC Press.

Well Sampling Procedures

Sampling of all well types—domestic, irrigation, livestock, and monitoring—includes protocols for wellhead inspection, well purging, sample collection and storage, quality assurance and quality control (QA/QC), and equipment decontamination. This section provides a general description of the protocol used by the Groundwater Protection Program during well sampling. A more detailed protocol is available by contacting Program staff. For newly installed monitoring wells, sampling does not take place until at least one month of time has elapsed since well installation and development, to allow for equilibration between the monitoring well and the aquifer formation.

Wellhead Inspection

Proper well construction and maintenance are required to prevent contamination from the ground surface. Thus, each sampling event begins with a thorough inspection of the wellhead and surrounding area. For monitoring wells, this includes checking the protective casing for damage or signs of tampering like a broken lock or well cap and inspecting the concrete apron poured around the protective casing for cracks or other damage. In the case of flush mount wells, it is important to note whether standing water is present under the well cap and the status of the riser cap. When a j-plug type cap is used on the riser and it is not properly installed, then standing water under the well cap may enter the well. If a well's integrity has been compromised and an inspection determines a potential for interference with sample collection or analysis, the well is either removed from the network, repaired, or, in the case of monitoring wells, re-installed.

The condition of domestic and irrigation well casing and seals also is inspected before sampling and potential problems noted in the sampling log. Nearby potential contamination sources—such as chemical storage or containers, chemigation equipment, livestock corrals, or septic systems—are recorded when necessary. With all wells, the general land use surrounding the well is recorded. The geographic coordinates of each sampling location is determined with a global positioning system and recorded.

Well Purging

Purging a well ensures no stagnant water or plumbing surfaces will interfere with the collection of formation quality water. Generally, for irrigation wells, the ideal time to sample is while the well is running for irrigation. Often the well must be turned on and run for a period of time. Most wells require five to 15 minutes for pH, temperature, and specific conductance to stabilize. Water samples are collected when three consecutive test readings stabilized to within 5%, which creates a reasonable assumption that the well casing and piping were purged and fresh formation water arrived at the sampling point. Due to drought conditions and/or water rights regulation, which have impacted numerous irrigation wells since 2006, it is difficult to always purge an irrigation well for the necessary time in the event that it is not running upon arrival. Much of the limitation is based on the well owner's preference on how long the well should run prior to collecting a sample. Personnel usually are able to run the well for three to five minutes but not much more. For the most part, irrigation wells that are part of the currently sampled Weld County dedicated monitoring network are only analyzed for nitrate, which is less vulnerable to inadequate purging than are pesticides or other organic compounds.

Monitoring well and domestic well purging involves the use of a flow-through cell and multi-parameter probe, which measures dissolved oxygen, pH, temperature, oxidation-reduction potential, and specific conductivity. Purging of a well with this equipment is complete after three consecutive readings are in agreement with the criteria in Table A-1. The measurement interval of the observer is dependent on the flow rate of the pump and the amount of time needed for a full flush of the flow-through cell. When the parameters are stable, the well is ready for sampling. All instruments used for purging undergo necessary calibration protocols using approved calibration standards. Calibration of the multi-parameter instrument is checked with a YSI Calibration Confidence Solution at the start of every sampling event between calibrations.

Since 2007, the Program has predominantly used a low-flow pneumatic bladder pump or a peristaltic pump for sampling monitoring wells; however, electric-submersible pumps had been used in all prior years. The Program's goal is to collect water samples that are as representative as possible of formation quality water. Using a low-flow sampling procedure with a bladder pump or peristaltic pump lessens in-well agitation and sediment unsettling, thereby providing the best opportunity to acquire an undisturbed, formation quality water sample.

Sample Collection and Storage

Bottles for the collection of anion or pesticide samples are purchased and inspected by staff at CDA's Biochemistry Lab. If necessary for stabilization of certain compounds, a preservative will be added to the sample bottle. When a preservative is used, the bottle is not rinsed and is not filled to zero head space so that preservative concentration is preserved. All sample bottles are adequately labeled to ensure proper identification of the sample site, date and time of collection, and lab analysis to be performed.

Upon adequate purging, outflow is diverted to a filtering apparatus—either a disposable filter in a plastic housing or a filter disk placed in a stainless steel filtering apparatus—via a three-way valve. Non-binder, Borosilicate, fiber glass filters with a 0.7 or 0.45 micron pass through, are used for filtration. However, not all samples require filtration.

Samples for nitrate analysis are collected in a translucent Nalgene bottle without preservative. Head space on any samples collected is minimized to prevent volatilization losses and the introduction of air to the

Table A-1. A flow-cell and multi-parameter probe are used to determine target stabilization criteria parameters for adequate purging of a well. When three consecutive readings are within the desired range for all four parameters, the well is purged. The reading interval is variable and is dependent on the pump flow rate. The accuracy and range for probes associated with the YSI 556-MPS are shown.

Parameter	Desired	YSI 556-MPS	
		Accuracy	Range
pH	± 0.2	± 0.2	0—14
sEC	± 5%	± 0.5% of reading or ± 0.001 mS/cm, whichever is greater	0—200 mS/cm
ORP	± 20 mV	± 20 mV	
DO	± 10%	0-20 mg/L: ± 2% of reading or 0.2 mg/L, whichever is greater	0—200 %
		20-50 mg/L: ± 6% of reading	200—500 %

samples. Care is taken to not excessively agitate the water and to prevent introduction of foreign matter such as air or airborne contaminants. To minimize degassing, the sampling port is operated at a low volume. In addition, samples for volatile constituents are collected first, nonvolatile organics second, nitrate and inorganic samples collected next, and dissolved metals samples collected last.

All samples are handled and preserved in accordance with CDA's lab requirements for each particular analysis. Upon collection, samples are secured and promptly placed in either a cooler with wet ice or an electric cooler set to maintain a temperature of less than 10°C. Care is taken to prevent breaking of samples during transport. Samples are always protected from undue exposure to light during handling, storage, and transport. Transport of the samples to the laboratory is completed within holding times—two days for nitrate and 14 days for pesticide samples, since time of collection.

Irrigation well samples are collected at a discharge point that has not been compromised by chemigation equipment or surface contamination. Domestic well samples are collected from hydrants, outside faucets, or other means available prior to any type of treatment such as a water softener. If possible, a sample point prior to a domestic well's pressure tank (if used) is collected to minimize alteration of the groundwater sample.

All samples are handled in accordance with CDA's laboratory chain of custody procedures after collection and identification. A completed chain of custody record accompanies the samples and is signed by both the sampler and the laboratory employee receiving the samples.

Equipment Decontamination

Any equipment used to collect a groundwater sample from more than one location is thoroughly decontaminated. Such equipment could include a pump, associated tubing, and filtering apparatus. In general, all potentially contaminated surfaces are triple rinsed with each of the following: Liquinox soap in tap water, laboratory grade deionized water, and 50/50 (v/v) methanol in deionized water. After decontamination, care is taken to prevent dust or foreign liquids, such as rain or snow, from coming in contact with sampling equipment.

Quality Assurance and Quality Control (QA/QC)

Program personnel collect quality assurance/quality control (QA/QC) samples of rinsate blanks, duplicate or blind duplicate samples, split samples, and when necessary, spiked samples. Field blanks are utilized for field QA/QC and subjected to the same conditions as all other collected samples. Duplicate, split, and spiked samples are prepared for lab calibration checks. When collecting a duplicate or split sample, bottles are filled 50% full in alternating fashion to ensure the two or more bottles are representative of the same water.

iStock.com

Groundwater well, Northern Colorado.

Following is a brief description of the four QA/QC sample types:

Rinsate Blank

A blank, or pure, water sample from sampling equipment is periodically tested to check the effectiveness of field decontamination procedures. Deionized water in decontaminated sampling equipment is tested, and should produce no contaminant results if effective field decontamination procedures are followed. The collection of a rinsate set includes a source water sample (laboratory deionized water) collected in the field and an equipment blank sample after the same source water has run through all equipment used for sample collection and having undergone decontamination. The frequency of this test is both at the beginning and end of a well network and at least once for every 20 sample locations.

Duplicate Samples

Duplicate groundwater samples, or multiple identical samples, are randomly and periodically collected and tested at the same lab, which produces nearly identical results if effective field collection and lab analysis procedures are followed. Occasionally, Program personnel will collect a blind duplicate sample in place of a duplicate sample to more strategically test efficiency of laboratory protocols while also still testing field procedure accuracy. The key difference between a duplicate and blind duplicate sample is the labeling of a blind duplicate does not clearly indicate to lab personnel that the sample is a duplicate. The frequency of collection is once for every 10 sample locations, and at least one blind duplicate is substituted in for each well network sampled.

Split Samples

Duplicate samples are periodically split between two labs for independent analysis, which produces nearly identical results if effective field collection and lab analysis procedures are followed. Also, a split sample may be collected in the event the Program needs to have analysis conducted at a separate lab because of inability to do so at CDA's lab. During collection of split samples, personnel fill bottles in a 50% alternating style to ensure samples are representative of the same water.

Spiked Samples

Spiked samples are samples with a known concentration of pesticide added to them and are submitted for lab analysis to assess laboratory performance. Spiked samples are prepared in duplicate in accordance with instructions provided by the spiking kit manufacturer. Usually, deionized water is used for the sample and the spiking agent is then added.

References

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Analytes, Laboratory Methods, and Minimum Detection Limits

Pesticide Common Name	Pesticide Trade Name	Pesticide Use	Chemical Type	Method	MDL (ppb)
2,4-D	Weed B Gone	Herbicide	PhenoxyAcid	LC/MS/MS	0.1
2, 4-DB	Butyrac, Embutox	Herbicide	Phenoxy acid	LC/MS/MS	0.5
2,4-DP	Celatox, DP	Herbicide	Chlorophenoxy acid	LC/MS/MS	0.5
3-OH carbofuran	BP[1]	I-A-N[2]	Carbamate	LC/MS/MS	0.25
Acetachlor	Harness	Herbicide	Chloroacetoalinide	LC/MS/MS	0.1
Acetachlor-ESA	BP	Herbicide	Chloroacetanilide	LC/MS/MS	0.1
Acetachlor-OA	BP	Herbicide	Chloroacetanilide	LC/MS/MS	0.25
Acifluorfen	Storm	Herbicide	Nitrophenyl ether	LC/MS/MS	0.1
Alachlor	Lasso	Herbicide	Chloroacetanilide	LC/MS/MS	0.1
Alachlor-ESA	BP	Herbicide	Chloroacetanilide	LC/MS/MS	0.1
Alachlor-OA	BP	Herbicide	Chloroacetanilide	LC/MS/MS	0.1
Aldicarb	Temik	I-A-N	N-Methyl carbamate	LC/MS/MS	0.1
Aldicarb sulfone	Standak	Insecticide	N-Methyl carbamate	LC/MS/MS	0.25
Aldicarb sulfoxide	BP	Insecticide	N-Methyl carbamate	LC/MS/MS	0.1
Aminopyralid	Milestone	Herbicide	Pyridine carboxylic acid	LC/MS/MS	0.5
Atrazine	AAtrex	Herbicide	Triazine	LC/MS/MS	0.1
Atrazine desethyl	BP	Herbicide	Triazine	LC/MS/MS	0.1
Atrazine desisopropyl	BP	Herbicide	Triazine	LC/MS/MS	0.25
Atrazine-OH	BP	Herbicide	Triazine	LC/MS/MS	0.1
Azoxystrobin	Abound	Fungicide	Strobilurin	LC/MS/MS	0.1
Bentazon	Basagran	Herbicide	Benzothiazinone	LC/MS/MS	0.5
Bromacil	Hyvar	Herbicide	Uracil	LC/MS/MS	0.25
Carbofuran	Furadan	I-A-N	N-Methyl carbamate	LC/MS/MS	0.1
Chlorantraniliprole	Coragen	Insecticide	Anthranilic Diamide	LC/MS/MS	0.1
Chlorimuron-ethyl ester	Classic	Herbicide	Sulfonylurea	LC/MS/MS	0.25
Chlorothalonil	Bravo	Fungicide	Chloronitrile	GC/MS	0.2
Chlorsulfuron	Glean	Herbicide	Sulfonylurea	LC/MS/MS	0.1
Clopyralid	Stinger	Herbicide	Pyradinecarboxylic acid	LC/MS/MS	0.5
Cyanazine	Bladex	Herbicide	Triazine	LC/MS/MS	0.1
Cyproconazole	Alto	Fungicide	Triazole	LC/MS/MS	0.1
Cyromazine	Larvadex	Insecticide	Triazine	LC/MS/MS	0.25
DCPA	Dacthal	Herbicide	Alkyl phthalate	GC/MS	0.2
Dicamba	Banvel	Herbicide	Benzoic Acid	GC/MS	0.5
Dichlobenil	Casoron	Herbicide	Benzonitrile	GC/MS	0.2
Dichlorvos	No-pest	I-A	Organophosphate	GC/MS	0.2
Diflufenzopyr	Distinct	Herbicide	Urea	LC/MS/MS	0.1
Dimethenamid	Outlook	Herbicide	Chloroacetamide	LC/MS/MS	0.1
Dimethenamid ESA	BP	Herbicide	Chloroacetamide	LC/MS/MS	0.25
Dimethenamid-OA	BP	Herbicide	Chloroacetamide	LC/MS/MS	0.1
Dimethoate	Cygon	I-A	Organophosphate	LC/MS/MS	0.1
Dinotefuran	Safari	Insecticide	Nitroguanidine	LC/MS/MS	0.25
Disulfoton	Disyston	I-A	Organophosphate	GC/MS	0.2
Disulfoton-sulfone	BP		Organophosphate	GC/MS	0.2
Disulfoton-sulfoxide	BP		Organophosphate	GC/MS	1
Diuron	Karmex	Herbicide	Phenylurea	LC/MS/MS	0.25
Ethofumesate	Nortranese	Herbicide	Benzofuran	LC/MS/MS	0.25
Ethoprop	Mocap	I-N	Organophosphate	GC/MS	0.2
Fenamiphos	Nemacur	Nemicide	Organophosphate	GC/MS	0.5
Fenamiphos-sulfone	BP	Nemicide	Organophosphate	GC/MS	0.5
Flufenacet	Axiom	Herbicide	Oxyacetamide	LC/MS/MS	0.1
Flumetsulam	Broadstrike	Herbicide	Triazolopyrimdine	LC/MS/MS	0.1
Halofenozide	Mach 2	Insecticide	Diacylhydrazine	LC/MS/MS	0.1
Halosulfuron-methyl	Permit	Herbicide	Pyrazole	LC/MS/MS	0.1
Hexazinone	Velpar	Herbicide	Triazine	GC/MS	0.5
Imazamethabenz-methyl ester	Assert	Herbicide	Imidazolinone	LC/MS/MS	0.1
Imazamox	Raptor	Herbicide	Imidazolinone	LC/MS/MS	0.1

Analytes, Laboratory Methods, and Minimum Detection Limits

Pesticide Common Name	Pesticide Trade Name	Pesticide Use	Chemical Type	Method	MDL (ppb)
Imazapic	Cadre	Herbicide	Imidazolinone	LC/MS/MS	0.1
Imazapyr	Arsenal	Herbicide	Imidazolinone	LC/MS/MS	0.1
Imazethapyr	Pursuit	Herbicide	Imidazolinone	LC/MS/MS	0.1
Imidacloprid	Admire	Insecticide	Neonicotinoid	LC/MS/MS	0.25
Isoxaflutole	Balance	Herbicide	Isoxazole	LC/MS/MS	0.1
Kresoxim-methyl	Stroby	Fungicide	Strobilurin	LC/MS/MS	0.25
Lindane	Gamma-HCH	Insecticide	Organochlorine	GC/MS	0.2
Linuron	Afalon	Herbicide	Urea	GC/MS	0.5
Malathion	Chemathion[2]	I-A	Organophosphate	GC/MS	0.2
MCPA	Agroxone	Herbicide	Chlorophenoxy acid	LC/MS/MS	0.1
MCPP	Kilprop	Herbicide	PhenoxyAcid	LC/MS/MS	0.1
Metalaxyl	Ridomil	Fungicide	Acylalanine	GC/MS	0.2
Metconazole	Caramba	Fungicide	Triazole	LC/MS/MS	0.1
Methomyl	Lannate	I-A	Carbamate	LC/MS/MS	0.1
Metolachlor	Dual	Herbicide	Chloroacetamide	LC/MS/MS	0.1
Metolachlor-ESA	BP	Herbicide	Chloroacetamide	LC/MS/MS	0.25
Metolachlor-OA	BP	Herbicide	Chloroacetamide	LC/MS/MS	0.25
Metribuzin	Sencor	Herbicide	Triazine	GC/MS	0.2
Metsulfuron-methyl ester	Ally	Herbicide	Sulfonylurea	LC/MS/MS	0.1
Nicosulfuron	Accent	Herbicide	Sulfonylurea	LC/MS/MS	0.1
Norflurazon	Evital	Herbicide	Pyridazinone	GC/MS	0.2
Norflurazon desmethyl	BP	Herbicide	Pyridazinone	LC/MS/MS	0.25
Oxamyl	Vydate	I-A-N	Carbamate	LC/MS/MS	0.25
Oxdemeton-methyl	Metasystox-R	Insecticide	Organophosphate	LC/MS/MS	0.1
Picloram	Tordon	Herbicide	Pyridine carboxylic acid	LC/MS/MS	0.5
Prometon	Primatol	Herbicide	Methoxytriazine	GC/MS	0.2
Propazine	Gesamil	Herbicide	Triazine	LC/MS/MS	0.1
Propoxur	Baygon	Insecticide	Carbamate	LC/MS/MS	0.1
Prosulfuron	Peak	Herbicide	Sulfonylurea	LC/MS/MS	0.25
Pyrimethanil	Distinguish	Fungicide	Anilinopyrimidine	LC/MS/MS	0.1
Quinclorac	Drive	Herbicide	Quinolinecarboxylic acid	LC/MS/MS	0.1
Simazine	Princep	Herbicide	Triazine	LC/MS/MS	0.1
Sulfentrazone	Spartan	Herbicide	Aryl triazolinone	LC/MS/MS	0.5
Sulfometuron-methyl ester	Oust	Herbicide	Sulfonylurea	LC/MS/MS	0.1
Sulfosulfuron	Certainty	Herbicide	Sulfonylurea	LC/MS/MS	0.1
Tebuconazole	Elite	Fungicide	Triazole	LC/MS/MS	0.1
Tebufenozide	Confirm	Insecticide	Diacylhydrazine	LC/MS/MS	0.1
Tebuthiuron	Spike	Herbicide	Urea	LC/MS/MS	0.1
Terbacil	Sinbar	Herbicide	Uracil	LC/MS/MS	0.1
Thiamethoxam	Cruiser	I-F	Neonicotinoid	LC/MS/MS	0.25
Triadimefon	Amril	Fungicide	Triazole	LC/MS/MS	0.1
Triallate	Avadex/Fargo	Herbicide	Thiocarbamate	LC/MS/MS	0.25
Triasulfuron	Amber	Herbicide	Sulfonylurea	LC/MS/MS	0.1
Trichlorfon	Dipterex	Insecticide	Organophosphate	LC/MS/MS	0.1
Triclopyr	Garlon	Herbicide	Chloropyridinyl	LC/MS/MS	0.5
Triticonazole	Charter	Fungicide	Triazole	LC/MS/MS	0.1
Vinclozolin	Ronilan	Fungicide	Dicarboximide	GC/MS	0.2

**EPA Method—EPA is responsible for evaluating analytical methods for drinking water and approving methods that it determines to meet agency requirements. An analytical method is a procedure used to analyze a sample in order to determine the identity and concentration of a specific sample component. Analytical methods generally include information on the collection, transport, and storage of samples; define procedures to concentrate, separate, identify, and quantify components contained in samples; specify quality control criteria the analytical data must meet; and, designate how to report the results of the analyses. Additional information can be found on the EPA Web site at http://www.epa.gov/safewater/methods/methods.html (EPA, 2006).*

***MDL—minimum detection limit; the lowest concentration of a substance that can be measured.*

[1] BP: breakdown product of another pesticide

[2] I-A-N-F: Compound maybe an insecticide, acaricide, nematicide, or fungicide.

Analytes, Laboratory Methods, and Minimum Detection Limits

Non-Pesticide Analyte	Chemical Type	Lab Method	MDL (ppm)
Alkalinity	inorganic	titration	1.0
Aluminum	dissolved metal	EPA 200.0	0.1
Barium	dissolved metal	EPA 200.0	0.1
Bicarbonate	inorganic	ALPHA 2320B	0.1
Boron	inorganic	EPA 200.0	0.01
Bromide	inorganic	not available	0.01
Cadmium	dissolved metal	EPA 200.0	0.01
Calcium	inorganic	EPA 200.0	0.1
Carbon (DOC)	inorganic	not available	not available
Carbonate	inorganic	ALPHA 2320B	0.1
Chloride	inorganic	EPA 300.0	0.1
Chromium	dissolved metal	EPA 200.0	0.01
Conductivity	inorganic	EPA 120.1	1 [umhos/cm]
Copper	dissolved metal	EPA 200.0	0.01
Fluoride	inorganic	not available	0.1
Hardness	inorganic	calculation	1.0
Iron	dissolved metal	EPA 200.0	0.01
Lead	dissolved metal	EPA 200.0	0.05
Magnesium	inorganic	EPA 200.0	0.1
Manganese	dissolved metal	EPA 200.0	0.01
Molybdenum	dissolved metal	EPA 200.0	0.01
Nickel	dissolved metal	EPA 200.0	0.01
Nitrate-nitrogen	inorganic	technicon	0.5 (1992-1994)
Nitrate-nitrogen	inorganic	EPA 300	0.5 (1994-2000)
Nitrate-nitrogen	inorganic	EPA 300	0.1 (2001-2005)
Nitrate-nitrogen	inorganic	EPA 300	0.05 ppm for 2006 to Present
pH	inorganic	EPA 150.1	0.1
Phosphorus	dissolved metal	EPA 200.0	0.1
Potassium	Inorganic	EPA 200.0	0.1
Sodium	Inorganic	EPA 200.0	0.1
Sulfate	Inorganic	EPA 300.0	0.1
Total dissolved solids	Inorganic	gravimetric	10
Zinc	dissolved metal	EPA 200.0	0.01

Instrument List:

CDA Biochemistry Laboratory (2007)

GC/MS Pesticides

- Hewlett-Packard 5890 Gas Chromatograph
- Hewlett-Packard 5972 Mass Spectrometer
- Hewlett-Packard 7673 Autosampler

GC Organophosphate Pesticides

- Hewlett-Packard 6890 Gas Chromatograph
- OI Analytical 5380 Pulsed Flame Photometric Detector
- Hewlett-Packard 7683 Autosampler

LCMS Pesticides (Carbamates, Phenoxy Acids)

- Thermo Finnigan Surveyor Autosampler
- Thermo Finnigan Surveyor Mass Spec LC Pump
- Thermo Finnigan LCQ Duo Mass Spectrometer

IC Anions (Nitrate, Nitrite)

- Dionex Autosampler
- Dionex GP40 Pump
- Dionex CD20 Conductivity Detector
- Dionex LC20 Chromatography Module

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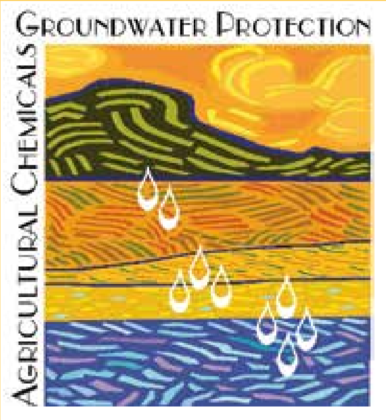

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